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THESIS

APPLICATION OF SPACE SHUTTLE PROJECT HERCULES IMAGERY IN THE INVESTIGATION OF SHIP CLOUD TRACKS

by

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September, 1993

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An assessment is made as to the utility of high-resolution imagery obtained via the Project HERCULES electronic still camera system, utilized onboard the Space Shuttle, toward the MAST Space Test Program investigation of ship-induced cloud tracks. Project HERCULES and MAST concepts are described. A detailed discussion is presented of the integration requirements, mission conduct, and payload support procedures involved in using the HERCULES system during the STS-56 mission to image potential shiptrack areas and Naval-related sites. Five HERCULES imagery cases are analyzed with feature measurements. Alternate camera systems are described, and then compared with the HERCULES system. Recommendations are made for the MAST payload. Although utility is seen in the geolocation and digital format offered by HERCULES images, its present configuration permits only limited use in the shiptrack and Naval-related applications. However, a firm procedural knowledge-base has been established for the MAST experiment.

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Application of Space Shuttle
Project HERCULES Imagery in the
Investigation of Ship Cloud Tracks

by

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ABSTRACT

An assessment is made as to the utility of high-resolution imagery obtained via the Project HERCULES electronic still camera system, utilized onboard the Space Shuttle, toward the MAST Space Test Program investigation of ship-induced cloud tracks. Project HERCULES and MAST concepts are described. A detailed discussion is presented of the integration requirements, mission conduct, and payload support procedures involved in using the HERCULES system during the STS-56 mission to image potential shiptrack areas and Naval-related sites. Five HERCULES imagery cases are analyzed with feature measurements. Alternate camera systems are described, and then compared with the HERCULES system. Recommendations are made for the MAST payload. Although utility is seen in the geolocation and digital format offered by HERCULES images, its present configuration permits only limited use in the shiptrack and Naval-related applications. However, a firm procedural knowledge-base has been established for the MAST experiment.

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I. INTRODUCTION

A. OVERVIEW

Since the onset of routine satellite-based Earth observations, linear cloud-like features, also known as anomalous cloud lines or cloud tracks, were observed in satellite imagery. Early documentation of this phenomena revealed ships to be the source of these cloud tracks seen over the ocean. These ship-induced tracks were observed to form in regions characterized by stratus clouds, stratocumulus clouds, or fog. [Ref. 1: p. 1; Ref. 2: p. 1]. Hand-held imagery from manned space flights, particularly the 1975 Apollo-Soyuz mission, also showed these features. A comparison of photographs taken on this mission with coincident satellite imagery of the same area revealed the additional potential that high-resolution manned-space imagery brought to the investigation of this phenomenon. [Ref. 3].

Research efforts over the last decade have served to further quantify and explain the meteorological and physical formation processes of the ship-induced cloud tracks. Likewise, the potential tactical implications of associating an observed shiptrack with its source have not gone unnoticed by military intelligence and research agencies. [Ref. 1:p. 2; Ref. 2:p. 2].

During the same time, advances in Charge-Coupled-Device (CCD) technology brought hand-held digital imagery into the realm of manned space flight. Digitally formatted imagery offers the investigator or analyst several advantages, including versatility in data transmission, image manipulation, and computer measurement techniques.

The possibility of utilizing digital hand-held manned space imagery to investigate ship cloud tracks emerged with the origination of two Department of Defense Space Test Program (STP) payloads. One payload is the Military Applications of Ship Tracks (MAST) experiment, jointly sponsored by the Office of Naval Intelligence (ONI) and Office of Naval Research (ONR). The other is Project HERCULES (Hand-held, Earth-oriented, Real-time, Cooperative, User-friendly, Location targeting, and Environmental System), a CCD camera with geolocation system, initially sponsored by the Naval Space Command. An opportunity for the author to conduct a "pilot study" to investigate the applicability of the Project HERCULES system to the MAST study materialized for Space Shuttle mission STS-56 "Discovery", flown during 8-17 April 1993.

This thesis describes the HERCULES system operation and capabilities, details the pre-mission and operational procedures utilized during the STS-56 mission, and examines post-mission results. An analysis of several examples of HERCULES imagery is conducted in order to assess the viability

and utility of the system toward the planned MAST payload. A comparison between the HERCULES camera system and other hand-held manned space flight cameras is made. Finally, procedural recommendations to facilitate the MAST STP study are provided.

B. BACKGROUND

1. Ship Track Phenomenon

Ship-induced cloud tracks are produced by the interaction of ship exhaust effluent with the air near the top of shallow moist marine layers, as well as by perturbations resulting from the wake and turbulence created by the ship itself [Ref. 4:p. 2]. The effluent and turbulence change the cloud structure such that the track exhibits an increased albedo. The physical formation process is postulated as follows: the ship activity causes an increase in the liquid-water content of the air along its track, which in turn causes the cloud droplet size to decrease. The number of cloud droplets therefore increases, and the corresponding scattering-to-absorption ratio increases. Cloud reflectivity in the infrared increases due to the decreased size of the droplets.

While ship track cloud lines are observed in the visible spectrum (.63 microns, Advanced Very High Resolution Radiometer, AVHRR Channel 1), their appearance is more pronounced in the near IR, particularly 3.7 microns (AVHRR Channel 3). The AVHRR imagery affords at best a resolution

of 1.1 KM. While this is sufficient for identifying individual tracks and their directional characteristics, it lacks the refined detail necessary for in-depth measurement and analysis of the track formation regions (track head, distance from source to observed track feature, etc.). Higher resolution imagery, on the order of tens of meters, is needed for these measurements.

Although the ship-track phenomenon is seen worldwide and throughout the year, it is more consistently observable in eastern ocean basins regions--e.g., the western coasts of the United States, South America, and Australia, and the eastern coast of Africa. A theory explaining the actual physics involved in forming this feature is under development. Research to date shows a favorable relationship between the ship activity and the cloud track formation.[Ref. 4:p. 2].

2. MAST Space Test Program (STP) Proposal

In order to more completely understand the ship track phenomenon effects, and to asses its military and intelligence applications, the ONR and ONI have jointly initiated a four-year investigative study which comprises a number of research topics and platforms. One facet of this research involves a STP experiment NIC-201, entitled Military Applications of Ship Tracks, or MAST, to be flown as a Space Shuttle (also referred to as the Space Transportation System--STS) mid-deck locker payload. Essentially, this experiment involves

astronaut crewmembers obtaining high-resolution imagery of shiptrack features through the use of hand-held cameras.[Ref. 4:p. 2]. Space Shuttle-based observations offer several desirable features which are unattainable by other means. These include:

- Worldwide high-resolution imagery obtained over a variety of environmental conditions, in a relatively short timespan.
- Near real-time response to cuing of potential developing conditions.
- The "man-in-the-loop" concept of serendipitous discovery on orbit, i.e., the potential for "seeing something" which might otherwise go undetected if a policy of sole reliance on satellite-based sensors were followed.

In particular, Shuttle missions with a 57 degree inclination will be pursued, as these afford a larger amount of total earth coverage. Coordination with other ongoing ship track field studies will be conducted. Also envisioned is the potential for a future MAST payload in which multispectral observations could be conducted in the form of a Shuttle "Getaway Special" payload bay experiment utilizing a wide-format camera and/or other dedicated instruments [Ref. 4:p. 3].

The concept of operations of the MAST STP includes:

- Comparison of these tracks with known Naval/NOAA vessel locations.
- Integration and relay of these locations into shuttle crew observation times.

- Determination of desired camera type (including HERCULES system) and lens/filter combinations to be utilized by the crew.

3. Project HERCULES

Concurrent with the MAST study formulation was the development and testing of the jointly sponsored (Navy, NASA, Army) STP experiment entitled Project HERCULES. The initial concept of the HERCULES system evolved from the desire to have some method of instantaneously affixing the time and earth coordinates of a hand-held image taken on orbit by an astronaut. Equally desirable is having the capability for both astronauts and ground personnel to view imagery taken on orbit on a near real-time basis.

Prior to the inception of this concept, the only method of determining the location and time of manned-space imagery was through post-mission analysis and reconstruction, relying on written and verbal recordings from the crew and through recognition of any known distinguishing geological or geographic features present in the image. Accurate geolocation of imagery lacking these associated data, or of open-ocean imagery, is nearly impossible. This difficulty is compounded when high-resolution imagery (with higher power lenses, and an associated reduced field of view) is attempted. In addition, with "conventional" photographic imagery, there is no real-time means of determining the quality of the photos as they are being taken.

In early 1985, the Latitude-Longitude Locator (L-Cubed) space sextant was jointly developed by the U.S. Navy and NASA. When coupled with a standard Hasselblad camera, the L-Cubed records the photograph's Earth coordinates and time. The L-Cubed was successfully flown on two Shuttle missions. However, some system limitations were noted.[Ref. 5:p. 1].

In particular, the device requires that the operator simultaneously view both the Earth horizon and the target during the shot--a difficult process to perform in a continually-moving space vehicle. The L-Cubed also requires the operator to measure the angle between the horizon and the target twice before imaging, which introduces error into the geolocation solution. The L-Cubed also reduces the magnification of the camera lens in use, while widening the field of view, making it unsuitable for object detection and classification. The search for an instrument which could effect rapid geolocation and suffer no loss of magnification spawned the development of Project HERCULES.[Ref.5:p. 1].

a. HERCULES System Components

The HERCULES system consists of five subsystems: the Electronic Still Camera (ESC), the Electronic Still Camera Box (ESCB), the HERCULES Inertial Measurement Unit (HIMU), the HERCULES Attitude Processor (HAP), and the Playback/Downlink Unit (PDU). Figure 1 shows a diagram of the HERCULES system components.

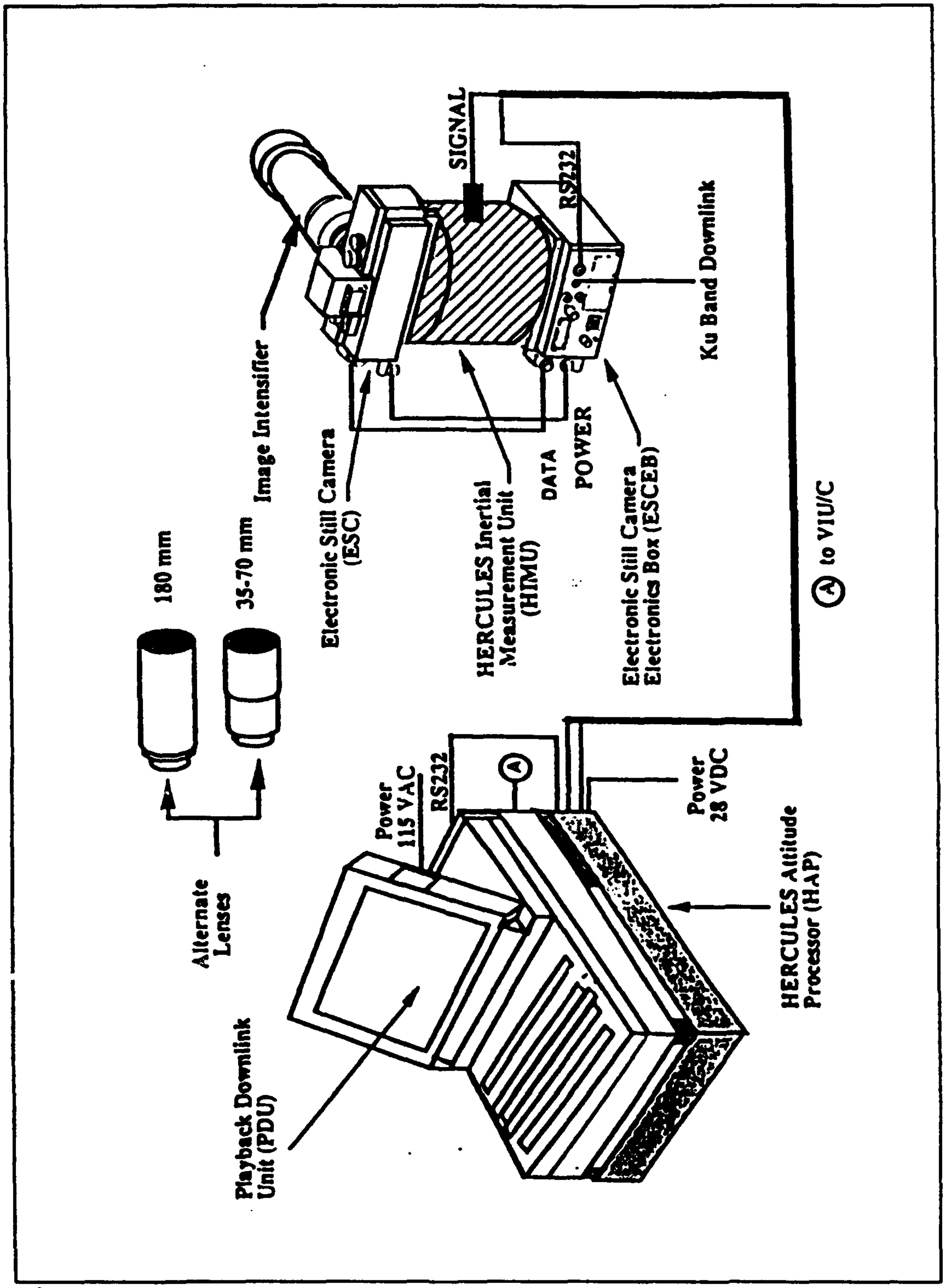


Figure 1. HERCULES System Components.
Source: Naval Research Laboratory, Code 8103.

The system descriptions which follow are excerpted from [Ref. 6:pp. 4-1 through 4-3]. The ESC is a modified Nikon F4 35mm camera with a CCD used for producing digitized images in place of film. The standard camera back has been replaced with a 1K by 1K pixel monochrome CCD array, digitizers, and controls.

The ESCB provides image storage and downlink capability, as well as power for the CCD array and digitizer electronics. Up to 39 images can be stored on each removable 40-Mbyte hard disk. The ESCB can interface with the Shuttle Ku-band for electronic downlink of images. The image downlink capability has several attractive applications, including on-orbit cuing of any phenomena of interest, imagery assessment during the mission, etc.

The HIMU is a Honeywell helium-neon, ring-laser gyro which measures inertial angular rates used by the HAP for determining the camera attitude. This information is then used by the PDU for determining the earth location toward which the camera is pointing.

The PDU (often referred to as the Payload General Support Computer, PGSC), a modified GRiD 1535 computer, contains a 386/387 microprocessor, 8 Mbytes RAM, and a 100 Mbyte hard disk (where the HERCULES software is resident). It has an image processing board which permits crew manipulation and display of ESC images. This includes tagging of desired images for downlink as well as text annotation of image files.

An assortment of camera lenses, filters, and accessories can be utilized. Combinations of these selected for MAST imagery will be addressed in Chapter II.

b. HERCULES Operation

The HERCULES system is stored in a Shuttle middeck locker, and removed and assembled on the Shuttle flight deck for on-orbit operation. Once assembled, the system must be initialized. The state vector (orbital position) emphemeris of the STS is obtained from the Mission Control Center (MCC) and uplinked to the crew. This state vector is then inputted to the PGSC, which propagates the state vector to the time when an event (e.g., shutter pulse) is received. The ESC attitude is then initialized on orbit by utilizing selected stars from the U. S. Naval Observatory's F5 star catalog (stored in system memory). The astronaut sights a known star, takes an image, rotates the camera 90 degrees, sights the same star and images it again. A second star is then selected and imaged.

With this information, an algorithm within the GRiD computes the camera's attitude, storing it for future reference. Thereafter, whenever the camera shutter is triggered, the associated time, attitude, ephemeris, and computed image central point (Earth location in camera cross hairs), are recorded with the image. [Ref 7:pp. 477-478].

The system's digital format necessarily requires a processing time of some 20-30 seconds in order to store the image and perform the necessary data exchanges between the ESC and the GRiD computer. This becomes the "waiting period" between image takes required of the operator.

System reinitialization is required every several hours due to accumulating errors between real and propagated STS orbital position. Reinitialization is also required if power to the HAP or PDU has been interrupted, or the systems are reset.

4. STS-56 HERCULES Objectives.

The Electronic Still Camera (ESC) portion of the HERCULES system was flown on five STS missions prior to STS-56. During four of these flights, assessments were made on several aspects of the system, including several lens/filter combinations and f-stop settings, the effect of the STS window on image resolution, and ground support image processing/distribution procedures. Since the HERCULES geolocation portion of the camera was not flown, no geolocation information was computed/attached to the images. ESC images were downlinked on two of these missions. [Ref. 8]. STS-53, on orbit in December, 1992, was the fifth time the ESC was flown, and marked the first time in which the HERCULES system was utilized with the ESC camera; however, this mission did not include any downlinking of images. The STS-56 mission

therefore became the first flight in which all of the capabilities of the HERCULES system were exercised.

STS-56 HERCULES Objectives included:

- Demonstrate HERCULES geolocation capabilities within 1 nmi.

- Demonstrate system resolution/pattern recognition capabilities by:

  -- varying lens/filter combination.
  -- utilizing different shutter speeds/aperture settings.
  -- changing operator technique.
  -- using ground processing image-enhancement techniques.
  -- varying target type.

- Verify system performance with ground truth.Demonstrate system downlink capability.

- Demonstrate image dissemination to user agencies.

- Demonstrate Shuttle/HERCULES response to user tasking. [Ref.9]

In particular, the demonstration of system downlink capability would include both scheduled downlink times and "real-time" downlink, (i.e., an astronaut would take an image, then downlink it to the ground support facility, which would in turn process and immediately relay the image to offsite users, including Fleet units).

As an adjunct to the above objectives, the author formulated a set of Naval Applications Objectives for STS-56:

- Investigate ship-generated atmospheric exhaust-wake tracks.

- Determine Lat/Long locating capability for ships at sea/in port.

- Determine resolution capability for ships at sea/inport.

- Investigate image-dissemination capability to Fleet units.

The distinct advantages offered by this system in the investigation of open-ocean phenomena are readily apparent: a time-tagged, geolocated, high-resolution, near-real-time downlinked image. It was realized that the 20-30 second time-delay between image takes was a potential limitation to the shiptrack investigation, since this is also the amount of time that a ground site is effectively in view from the Shuttle. However, with its combination of capabilities, the HERCULES system was still visualized as an overall excellent tool for the MAST STP application. This application also tied in nicely with the other STS-56 HERCULES objectives.

Since the MAST STP was not yet manifested for a Shuttle flight (but is projected for 1994), the complete MAST study involving dedicated ships and a variety of cameras could not be conducted on the STS-56 mission. However, HERCULES high-resolution shiptrack imagery could be obtained, and near real-time Navy and NOAA reported ship positional information could be utilized, as a part of the HERCULES system evaluation. This course of action was pursued. Key considerations included:

- Type of lens/filter combinations to be utilized.
- Field-of-view size desired.
- Type and frequency of ship reporting data to be utilized.
- Ground support facilities available.
- Planning and "lead-time" procedures required.

C. OPERATIONAL CONSIDERATIONS.

A method of achieving the HERCULES Naval Objectives stated above was pursued, with particular concentration focused on obtaining some high-resolution shiptrack imagery. First, utilization of known ship type, positional, and meteorological data was considered preferable to the alternative of "back-fitting" data obtained from various archives. Some means of obtaining this data was required. Also, access to the various weather satellite imagery was needed. The particular type of lens and filter combinations to be used by the astronaut when imaging a ship or shiptrack required specification. Also, a workable means of relaying a downlinked image to an afloat unit required implementation.

From a practical standpoint, it was realized that the chances having a predetermined (but non-dedicated) vessel on station under the proper cloud conditions, coinciding with a Shuttle orbit and a scheduled HERCULES crew-utilization window were remote. However, it was felt that some utility could be gained by being cognizant of deployed Navy or NOAA vessel operating areas during the mission timeframe, making a determination of their wake-imaging potential based on the available weather satellite information, and relaying these coordinates and time-to-image to the crew.

The STS-56 HERCULES evaluation provided the opportunity to conduct a "pilot study" of the applicability of Shuttle-based high-resolution imagery toward the MAST program. At the very

least, valuable procedural experience for the dedicated MAST payload planned for 1994 was gained. To assist in facilitating this plan, MAST representatives from the Naval Postgraduate School (the author and his advisor) were present at JSC during the mission. Chapters II and III describe the various integration planning requirements, operational processes, and support procedures involved with the HERCULES payload during the STS-56 mission.

II. INTEGRATION

A. OPERATIONAL REQUIREMENTS

In order to attain the proposed Naval objectives and facilitate a study of the shiptracks using the HERCULES system, several pre-mission planning steps and procedures were required. These included: formation of a preliminary "target list" of areas and sites to be imaged, obtaining ship positions, arrangements for downlinked image dissemination, security considerations, and ground support manning for HERCULES target replanning. Under the STP, military payloads flown aboard the Space Shuttle are handled by the U.S. Air Force Space and Missile Systems Center (SMC/CULH) Operating Location (OL-AW) branch based at Johnson Space Center in Houston, Texas. This office serves as the primary point of contact for military-related aspects of HERCULES.

1. Preliminary Target List

One STP documentation requirement is the Payload Integration Plan (PIP), which identifies crewmember activities associated with a payload [Ref. 10:p. 170]. For the HERCULES payload, PIP Annex 2 contains a list of candidate targets to be imaged with the HERCULES system. Accordingly, project users/sponsors were requested to provide input to this list for the STS-56 mission. On behalf of the Naval sponsor (CNO

N632- Navy TENCAP), the author provided an input of sites and regions considered appropriate to the stated Naval applications; suggestions for sites conducive to STS-56 overall HERCULES objectives were also included. The Naval targets consisted primarily of ports, straits, and channels considered to be well-known in terms of distinguishing features or visual contrast, geographic coordinates, and/or significant ship activity. A list utilized for the Maritime Observation of Ships at Sea (MOSES) experiment flown on STS-28 served as a baseline for this input.

Barrios, Inc., a contracted firm supplying some facets of ground support for HERCULES, compiled a master list of targets, placed it into a computer master file and ran it against an algorithm containing Shuttle orbital ephemeris data to compute the Station Contact Summary List. This list included such parameters as: orbit number and time in view, sun elevation angle, degrees from nadir, etc. for each individual target. A representative listing of pre-mission STS-56 target sites is found at Appendix A.

2. Ship Coordination

It was recognized that several of the Naval objectives could be better facilitated if information (dimensions, power plant, course, speed, location) about a target vessel or vessels was available prior to or during the mission. While such information on civilian or NOAA ships was unclassified,

certain portions of it (namely, position, course, speed) concerning U.S. Navy vessels was classified. Therefore, a means of obtaining and properly handing this information was required.

Since NOAA vessels maintain detailed meteorological and oceanographic records as a matter of routine, requests for support were made to the NOAA Atlantic Marine Center in Norfolk, Virginia, and the Pacific Marine Center in Seattle, Washington. While underway, NOAA vessels provide noon position reports to their respective Marine Center. The reports also contain the wind speed/direction, sea swell direction and height, and barometric pressure. Detailed meteorological observations are recorded on the ship's deck log, and on some vessels, are automatically recorded via Scientific Computer System (SCS) computer. Arrangements were made for the author to receive FAXed copies of the noon position reports at JSC during the mission from both NOAA Marine Centers. More detailed records would be requested of those ships whose positions at the time matched that of a Shuttle orbital overflight, in anticipation of obtaining an image of either the ship itself or any anomalous cloud track it might be producing.

A similar method of obtaining U. S. Navy ship positions was required. While this information is available on the Joint Operational Tracking System (JOTS), the system and its associated information are classified. Lack of

sufficient leadtime and logistical security considerations precluded the installation of a JOTS terminal at JSC Houston. An additional consideration was that the STS-56 flight was an unclassified mission; therefore, no classified positions of Navy ships could be passed to the crew. As an alternative, arrangements were made for the author to obtain Navy ship positions from the Naval Space Surveillance Center (NAVSPASUR) watch team in Dahlgren, Virginia, via the STU-III (secure) telephone available at the Air Force SMC office at JSC. NAVSPASUR has access to both Atlantic and Pacific theater ship positions; in concert with a CINCPACFLT-NAVSPASUR agreement, permission for release of the Pacific Fleet information by NAVSPASUR was required and obtained. The positional information was not relayed to the STS-56 crew, but recorded for post-mission analysis.

3. Support Personnel

The Air Force SMC office, working with the HERCULES Project Manager at the JSC Life Sciences Project Division, coordinated the assignment and tasking of personnel required for STS-56 HERCULES support. There were essentially four groups: 1) Secondary Payload Operations Manager (SPOM) which interfaced directly with Mission Control; 2) SPOM Support which provided updated state vectors and the computer-validated target list for uplink to the Shuttle; 3) ESC representatives for coordinating camera-related problems,

downlinked imagery, and imagery dissemination; and 4) the HERCULES Replanning Group to formulate the revised list of potential target sites for imaging. Air Force and JSC personnel served as the SPOM representatives. Personnel from the Naval Research Laboratory (NRL) provided state vector computations, while contract support supplied the validated target lists. Personnel from JSC's Electronic Still Camera Laboratory and the Life Sciences Support Division provided the ESC support. The HERCULES replanning team was composed primarily of representatives from the Naval Reserve Naval Space Command 0166 Detachment Houston. The Earth Observation Laboratory (EOL) at JSC provided world-wide weather evaluations (mainly cloud cover predictions for potential target sites). A more detailed description of the EOL capabilities is contained in Chapter III. The author assisted the Replanning Group in specifying areas considered conducive to shiptrack formation.

4. Image Dissemination to the U.S. Navy

One of the overall STS-56 HERCULES objectives was the dissemination of downlinked imagery to outside users, to include some component of the U. S. Navy, preferably a vessel afloat. This was to serve as a further demonstration of the operational potential of the HERCULES system, and was of particular interest to the Navy TENCAP office. Arrangements were necessary in order to establish the proper type of data

communications link to be utilized. The majority of these discussions were handled by the NASA's JSC ESC Laboratory/HERCULES Project Manager's Office and representatives of the Naval Electronic Systems Engineering Activity (NESEA), St. Inigoes, Maryland, with the author providing initial Navy points of contact. Key considerations included:

a. Systems Compatibility

The standard Navy system used to process and transmit/receive digital imagery is the Fleet Imagery Support Terminal (FIST), which uses the National Imagery Transmission Format (NITF) for its data structure. In order to utilize this system, the HERCULES image required conversion from its TARGA format into NITF.

b. Communications

A medium for transmitting the image from JSC to a Navy site had to be selected. Existing operational communications circuits for FIST are UHF Satellite (2400 Bps), SHF Satellite (9600 Bps), and Secure telephone (STU III) (2400, 4800, 9600 Bps) via INMARSAT. [Ref. 11:p. 2].

c. Physical Capacity

Possible limitations of bandwidth availability, disk storage capacity, and amount of communications satellite dedicated time determine whether image compression is

necessary, as well as the time of day and number of images which can be sent to a Fleet unit. [Ref. 11:p. 2].

d. *Image Routing*

Besides the physical image transmission considerations, a determination of the appropriate avenue of routing the imagery to a Fleet unit was required. In order to service a wider range of users, while still allowing individual user flexibility, HERCULES image and data dissemination was accomplished through the use of the INTERNET computer communications network. For transmission to afloat Naval units, Navy personnel located at the Atlantic Intelligence Center (AIC), Norfolk, Virginia, transferred the imagery from the INTERNET account, converted it to NITF, and transmitted it via one of the available Fleet communications nets at selected times as available. [Ref. 12]. Participating afloat units were identified as USS "America" and USS "Guam". Other Fleet participants were Commander, Joint Task Force Four (CJTF4) and U.S. Commander in Chief, Atlantic Fleet/ Joint Intelligence Center (CINCLANTFLT/JIC). [Ref. 13].

5. Potential ER-2 Ground Truth Underflight

Ground position verification, or "ground truth", is an important element in imagery analysis. Ground truth provides the analyst with a known datum from which to base dimensional and positional measurements. For overland images, it is typically achieved through the identification of recognized

features (landmarks or structures). However, it is harder to obtain ground truth for images of features taken over open ocean (e.g., clouds), where no such sites exist. Alternatively, ground truth can be achieved by obtaining simultaneous imagery from a platform which has maintained an accurate positional record.

The author investigated the possibility of obtaining coincident ground truth imagery from the ER-2 high-altitude research aircraft based at the NASA-Ames Research Center, Moffett Field, California. Several multispectral imaging systems are available with the ER-2, including a CCD camera system with filters. A comparison of coincident HERCULES and ER-2 CCD imagery had potential value from a remote sensing standpoint. While the ER-2 is planned for use in a 1994 MAST field study, no funding was available for a dedicated flight during the STS-56 mission. However, the possibility existed of obtaining imagery taken during a short (one-two hour) maintenance check flight near the California coast, if such a flight could be coordinated during the mission.

B. SATELLITE IMAGERY SUPPORT

As mentioned on Chapter I, ship-induced cloud tracks are seen in weather satellite imagery worldwide. This satellite imagery cues MAST investigators as to which areas are conducive to shiptrack formation at any particular time. Without access to satellite imagery, the MAST investigator has

no means of planning potential imagery data takes, let alone providing cuing to on-orbit astronauts. Therefore, it is useful (necessary) to have a fundamental knowledge of the satellites which can provide this cuing information. Table 1 summarizes pertinent information on those satellites available for use.

The NOAA and DMSP satellites are commonly called "polar orbiters" due to their approximate 99 degree (retrograde) inclinations. Their orbital altitudes provide any given area on Earth the opportunity for two "passes" of a particular satellite per day, approximately 12 hours apart (although the satellite viewing angle may be oblique). In addition, their retrograde sun-synchronous orbits ensure that the observation of a particular location will occur at about the same local time every day, which is useful for planning any shiptrack data takes.

The geosynchronous satellites offer continuous coverage of a particular area, which is important in observing time-related phenomena such as shiptracks, but suffer from decreasing resolution away from the orbital subpoint. Several different geostationary satellites are needed for full Earth coverage.

By skillfully combining imagery from all of these systems, the MAST investigator can monitor regions of potential shiptrack formation on a worldwide basis.

TABLE 1. SHIPTRACK INVESTIGATION SATELLITE SUPPORT.

SATELLITE	ORBIT	INCLIN	APPLICABLE IMAGERY/RESOLUTION
NOAA-10	860 KM, sun-sync	99 deg	5 channel AVHRR Visible & IR: 1.1 KM
NOAA-11	"	"	"
NOAA-12	"	"	"
DMSP	850 KM, sun-sync	98.7 deg	Visible: 0.6 KM IR: 0.6 KM
GOES	Geostationary	0 deg	12 channels;Vis:1KM IR: 8KM
METEOSAT	Geostationary	0 deg	3 chan: Vis: 2.5 KM IR: 5 KM
GMS	Geostationary	0 deg	Visible: 1.25 KM IR: 5 KM

Source: Dr. Carlyle Wash, Dept. of Meteorology, Naval Postgraduate School, Lecture notes: "Remote Sensing--Glossary of Current and Future Satellite Systems and Sensors," January, 1992.

C. LENS/FILTER SELECTION

One of the key considerations for the STS-56 HERCULES payload was the complement of lenses and filters that would be used on orbit, and the conditions under which they would be utilized. The following subsections provide some brief background information on camera lenses and filters, and relate these to the specific case of the HERCULES ESC. Lens focal length, ground resolution, and field of view calculations are provided at the end of subsection 1.

1. Lens Selection Factors

Several different lenses (50, 180, and 300mm; 300mm with 2X extender, and 35-70mm zoom) had been utilized with the

HERCULES ESC on previous missions, with varying results [Ref. 8]. For the STS-56 mission, a selection from among these same lenses would be used, as well as a 1000mm lens and an Image Intensifier, in an attempt to determine their practical limits of usefulness, as well as to verify the optimum shutter speed and aperture settings for each lens type. Experiments with the Image Intensifier would involve taking shots of dark or low-light areas (e.g., cities/ports at night or near the Earth's terminator).

a. *Shutter Speed*

From the previous missions, it was known that Shuttle motion generally tended to limit resolution capabilities, and that Earth shots seemed to improve when a shutter speed of 1/500 second with f-stop F/8 was used [Ref. 8]. Also, as with "conventional" Earth-based photography, the higher the lens power, the higher the shutter speed required to prevent jitter/smearing of the image. The "tradeoff" is that for longer lenses (higher power), less light which reaches the image recording medium, so either a wider aperture (lower f-stop number) or slower shutter speed is required to prevent an underexposed image.

b. *Field of View (FOV)*

Field of view (the "area" seen in the camera viewer) is another factor in lens selection. A higher power lens offers a correspondingly narrower field of view; the

opposite is true for a lower power lens. This fact greatly influences an astronaut's ability to acquire and properly image a desired target from orbit. The astronaut must look in the general area of the intended shot, aim the camera, acquire the point of interest within the associated field of view, focus and take the image--all while attempting to keep the body motionless in near-zero gravity as the Shuttle moves along its orbit at 7.73 km/s (which equates to some 250nmi per minute over the ground at nadir). An astronaut using a high power lens would likely experience more difficulty in acquiring the target, and have less time to keep it focused within the lens' field of view.

c. Ground Resolution

Desired ground resolution is another factor in lens selection. A higher power lens provides a smaller resolution capability, i.e., the distance at which two objects can be distinguished as separate bodies is smaller. From the above discussion, it follows that in order to increase the probability of framing the object of interest within an image, a lens with a wider field of view would be in order; however, the tradeoff is that the image would be of a lower resolution.

d. Physical Size

Weight and space requirements are ever-present factors affecting any space-launch activity, and camera lens size is no exception. Higher power lenses are generally

larger, longer, and more cumbersome to maneuver into position--an important concern in the relatively confined environment of the Space Shuttle.

e. *Overhead Windows*

A final consideration, and one which specifically concerns Shuttle-based imagery, is the effect of the Space Shuttle overhead windows on camera lens resolution performance. The Shuttle overhead windows were not designed for optical-quality, and tests show that they could significantly affect the quality of medium- aperture optical system imagery [Ref. 14:p. 7]. While shorter focal length lenses with varied aperture settings showed no statistically significant degradation in resolution, such degradation was encountered with a 600mm lens at specific aperture settings and a 30 degree incidence angle. [Ref.14:p. 39]. In particular, the

> condition for which maximum resolution was achieved through the window assembly (was) with the 600mm focal length and aperture of 2.95 in. (f/8). At a 160 nmi orbit, this would correspond to a ground resolved resolution of 9.0 ft. Without the window, 8.0 ft would be expected. A moderate degradation in resolution is induced by the window assembly.[Ref.14:p. 39].

It was also noted that specific Shuttle windows had their own particular aberration and diffraction characteristics, and that "...the cutoff point, at which increasing aperture fails to increase resolving power, still is unclear." [Ref. 14:p. 45].

f. Calculations

For the HERCULES shiptrack investigation, it was decided that three specific lenses should be employed: 50mm, 180mm, and 300mm. These would provide a combination of images, some with a wider field of view to give a greater probability of getting more of the ship track in the frame, and also some with higher resolution, which could reveal information about the shiptrack formation processes near the head of the track (and perhaps even the ship itself). Table 2 provides more specific information on the calculated theoretical field of view and ground resolution possible with each of these lenses, based on a nominal 160 nmi orbit.

TABLE 2. HERCULES ESC GROUND RESOLUTION FOR 160 nmi ORBIT.

LENS (mm)	FIELD OF VIEW (nmi)	GROUND RESOLUTION (m)
50	48	89
180	13	24
300	8	14.8
300 with 2X (600)	4	7.4
300 with 1.4X (420)	5.7	10.57
1000	2.4	4.44

These data were computed using the relationship:

$$\frac{\text{Orbiter-to-Earth-Distance}}{\text{Ground Resolution}} = \frac{\text{Focal Length of Lens}}{\text{Pixel Size}}$$

Pixel size for the HERCULES ESC is 15 microns. Solving the above for Ground Resolution gives the number of meters/pixel.

When multiplied by the number of pixels per each line of the image (1024 for HERCULES ESC), and with appropriate unit conversions, the outcome is Field of View in nmi. A sample calculation follows:

Given: Orbiter-to-Earth Distance = 160nmi = 296,300m

Pixel size = 15×10^{-6} m/pixel

Lens Focal length = 180 mm = 180×10^{-3}m

$$\text{Ground Resolution} = \frac{(296{,}300\text{m}) * (15 \times 10^{-6}\text{m/pixel})}{180 \times 10^{-3}\text{m}}$$

$$= 24.7 \text{ m/pixel}$$

$$\text{Field of View} = (24.7\text{m/pixel}) * (1024 \text{ pixels})$$
$$= 25{,}293 \text{ m}$$
$$= 13.7 \text{ nmi}$$

2. Filters

An analysis and recommendation for an appropriate set of filters was conducted by Dr. Jonathan Gradie, Senior Scientist, SETS Technology, Inc. Considerations for selection included:

> (1) ease of use, i.e. require little or no astronaut training, (2) availability of filters and materials, i.e. would not require mechanical or electronic changes to the current system and (3) applicability to terrestrial remote sensing problems in such a way (as) to demonstrate the utility of the hand-held electronic camera applied to photography from orbit.[Ref. 15:p. 1].

Other factors included the spectral reflectivity of the various types of targets to be imaged (e.g., vegetation, land, water) and their corresponding photometric contrast

characteristics, shutter speed, and required f-stop setting. The study presented a model of the filter transmission characteristics by creating a

> radiative transfer model that includes the solar flux, atmospheric absorptions (two passes on a clear northern temperate day) and the shuttle bay window convolved with the HERCULES CCD response.[Ref. 15:p. 3].

The results of this model are graphically depicted in Figure 2 at the end of this chapter.

The resultant filters suggested by the study were chosen because of their semblance to remote sensing bands presently in use, compatibility with the HERCULES camera lenses, simplicity of handling, and ease of purchase.[Ref. 15:p. 4]. A list of filters was compiled, with individual filters referenced by letter/number descriptors of H1 through H10. The set of filters to be purchased and used on the mission was selected from this list by members of the HERCULES Project Manager's Office. This selected set, along with the individual filter specifications, is compiled in Table 3.

TABLE 3. SELECTED SET OF HERCULES ESC FILTERS--STS-56.

FILTER	ANALOG	CENTER WAVELENGTH	FULL WIDTH HALF MAXIMUM	SCHOTT GLASS COMPOSITION	REMARKS
H3	Thematic Mapper Band 3 (630-690nm)	651nm	620-690nm	BG40(1mm)+RG610 (3mm)	Max contrast betwn vegetation(dark) and soil/manmade materials
H4	Thematic Mapper Band 4 (760-900nm)	762nm	730-810nm	RG9 (3mm)	Max contrast betwn vegetation (reflective) and soil/manmade materials
H9	Nimbus 7 Filter#3 (535-565nm)	566nm	540-580nm	OG530(3mm) +VG14(1mm)	Ocean pigment/vegetation applications
H10	Spectrally neutral polarization filter	N/A	<400nm to >800nm	Nikon polarizing filter	Increasing photometric contrast in scene

Source: [Ref. 15:pp.8-9].

For imaging shiptracks and potential shiptrack areas, the H3 and H4 filters were considered to be the most appropriate. The H3, with a full width half-maximum of .620-.690 microns, more closely resembles the NOAA AVHRR Channel 1 (.63 micron) window in which shiptrack features previously have been observed. The H4 filter, with a full width half-maximum of .730-.810 microns and center wavelength of .762 microns, provides a contrast reversal to the H3 filter. It potentially provides a "different" view of any shiptrack feature. For example, a detail which would not otherwise appear in an image taken with the H3 filter (or with no filter at all), might stand out in a similar image taken with the H4 in use. Since the filter only permits specific wavelengths to pass through, then only the energy associated with those wavelengths will be recorded. A particular feature (e.g., cloud track) might only register a given reflectance (energy), and thus be seen only at that associated wavelength with that filter. Also, wavelengths transmitted through this filter

would be at the upper limit of the Shuttle cabin window visible light transmittance curve, and closest to the near-IR wavelength [Ref. 16:p. 13]. The top graph in Figure 3 at the end of this chapter depicts the cabin window transmission curve. The possibility also existed that the actual ship track head, or the even the ship itself, might better stand out when using either of these filters. For example, since the H3 filter was designed to provide contrast between dark vegetation and highly reflective materials (such as man-made objects) [Ref. 15:p.7] the same reasoning could be used with an image taken of a ship against a dark ocean background.

It should be noted that the STS also has an optical-quality window located in the cabin mid-deck hatch. This window does not have the protective coatings found on the other cabin windows. Therefore, special flight equipment (mount, hood, shroud) is required (and must be manifested) before the side hatch window can be utilized in flight.[Ref 16: p.32]. The bottom graph in Figure 3 depicts the side window transmission curve. Because of its location, use of this window is highly dependent on the Shuttle attitude, so it may be of limited use during a particular flight. The side hatch window was not manifested for STS-56, so it did not a factor into the shiptrack investigation.

The selection of the appropriate lens/filter combinations used on the mission was based on three key criteria. First, the purpose of the image was needed, i.e.,

was the image intended for testing ground resolution capabilities, geolocation accuracy, or other purposes (scientific investigation, filter comparison, etc.)? Second, would the lens and filter be physically compatible (size-matched)? Finally, how much time would be available or required to switch the lens and/or filter between shots?

It was decided that ground resolution capability should be tested with the 300mm lens and no filter, in order to provide a faster shutter speed (and consequently a smaller chance of image blurring). It was also noted that the 300mm lens was not compatible with the H2 or H3 filters, due to the thickness of the Schott glass combinations comprising these filters when compared to the available attachment distance on the forward lens body. Geolocation could be conducted with the 180mm lens, and any of the filters. Scientific investigation users (e.g., the shiptrack investigation) could specify desired combinations beforehand, and update these as necessary during the mission. The numbers of images taken with the various combinations of lenses/filters would be monitored during the course of the mission to ensure adequate numbers of each were obtained for later analysis. [Ref. 17]. A priority list for the shiptrack investigation, along with suggested combinations for the other naval objectives, was provided by the author to the STS-56 crew prior to the mission, and is listed in Table 4.

TABLE 4. HERCULES SHIPTRACK IMAGERY LENS/FILTER PRIORITIES.

PRIORITY	LENS	FILTER
1	50mm	H4
2	50mm	H3
3	180mm	H4/H3
4	300mm	H4
Geolocation of Ships at Sea/In port: 180 mm, no filter. Resolution of Ships at Sea/In port: 300mm or 1000mm, no filter. 1000mm suggested only near ports/harbors due to its correspondingly small field of view.		

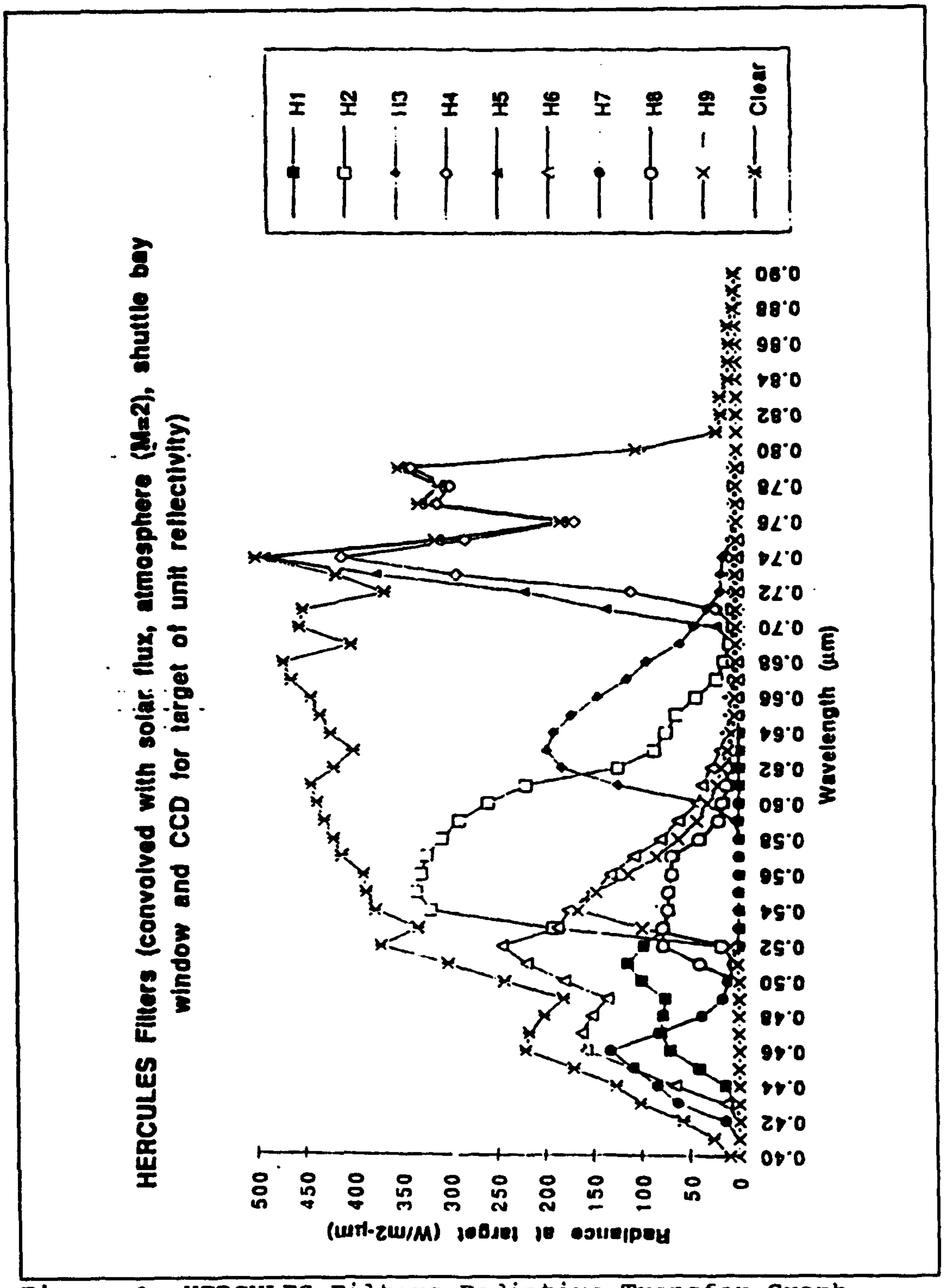
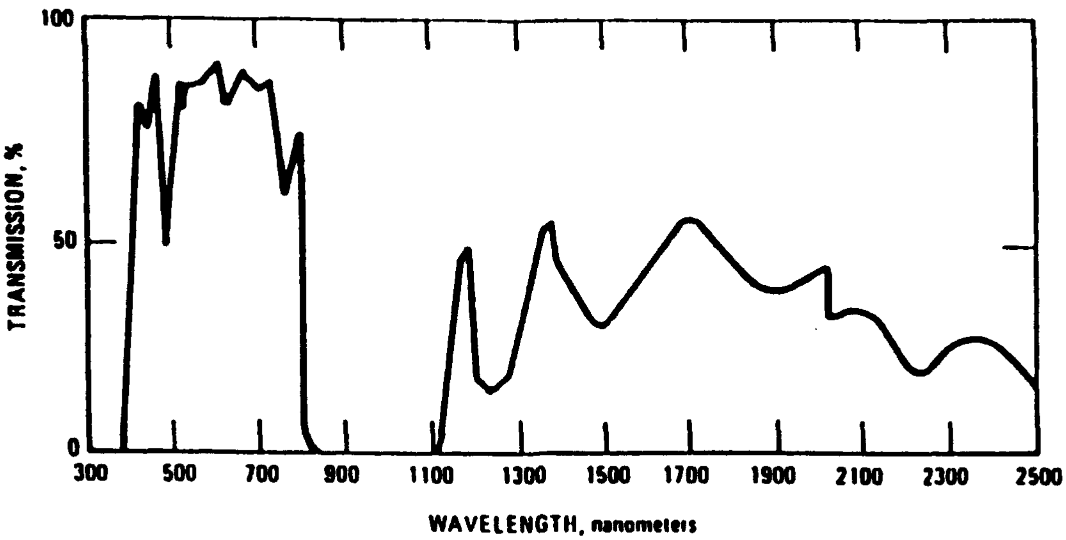
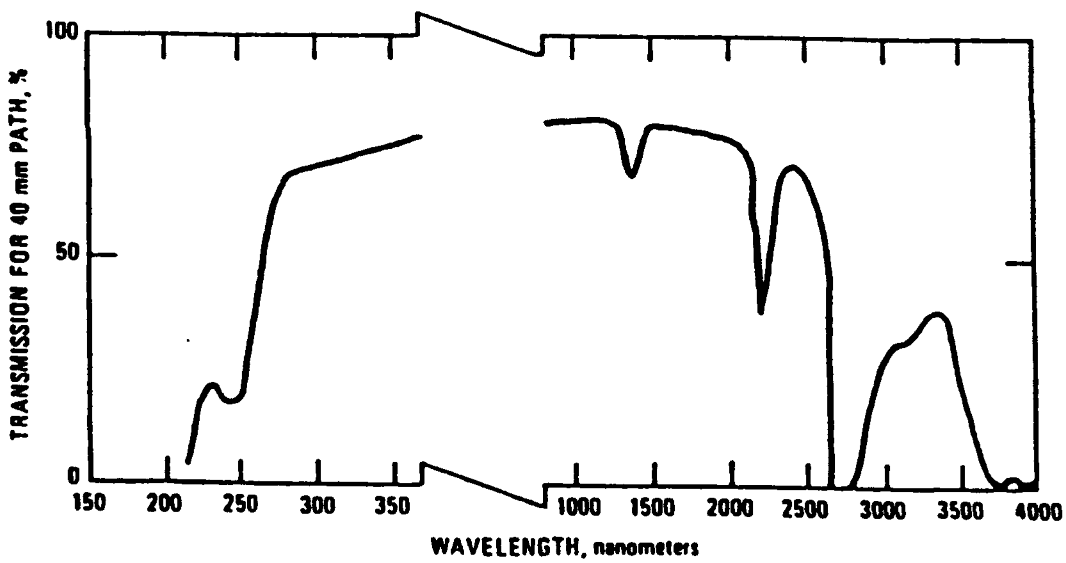


Figure 2: HERCULES Filters Radiative Transfer Graph. Source: [Ref. 15].



Shuttle Flight Deck Aft and Overhead Windows
Transmission Curve.



Shuttle Side Hatch Window Transmission Curve.

Figure 3: Shuttle Window Transmission Curves.
Source: [Ref. 16].

III. MISSION CONDUCT/PAYLOAD SUPPORT PROCEDURES

A. FLIGHT PLAN DESCRIPTION

A key publication included in the voluminous amount of documentation for any STS mission is the Flight Plan, which contains the on-orbit timeline covering the entire flight. The two sections of the STS-56 Flight Plan which served as ready references for the HERCULES experiment were the Summary Timeline and the Detailed Timeline. These sections provided a continuous profile of the flight activities of each STS-56 crewmember. Examples of each are found in Appendix B.

Each page of the Summary Timeline includes a 12-hour depiction of: two linear time-traces (one local Houston time, CST, and one Mission Elapsed Time, MET) in five minute increments, crewmember activities profile by position, Earth trace profile, and bar lines depicting day/night areas, orbit number, Shuttle attitude, and TDRS (Tracking and Data Relay Satellite) coverage. [Ref. 18]. Rough planning information could be quickly obtained by consulting the appropriate page of the Timeline. However, since it was published for an original launch date of 11 March 1993 (actual mission launch was 8 April 1993), and because of changes in actual launch time, Shuttle attitude, and crew activity schedules, its accuracy was slightly diminished.

The STS-56 crew was divided into two teams, Red and Blue, so that one shift was awake at all times during the mission. This provided the HERCULES experiment with an advantage, since more time could be allocated for utilizing the system. Two crewmembers (one per each shift) were the primary HERCULES operators: Pilot (PLT) Steve Oswald on the Blue team, and Mission Specialist (MS2) Ken Cockrell on the Red team.

The HERCULES payload enjoyed another advantage by being manifested on the STS-56 mission, in that a majority of the mission was flown with the Shuttle in an "Earth-looking " attitude. During orbital flight, the STS attitude control axes are: +X=toward the nose, +Y=starboard direction, +Z=toward the landing gear. [Ref.16:p. 11]. The "Earth-looking" attitude is indicated on the Summary Timeline by the notation "-ZLV" (minus Z local vertical), meaning that the Shuttle overhead observation windows were facing the Earth--the most desirable position for taking Earth-looking images.

B. EARTH OBSERVATION LABORATORY (EOL) INTERFACE

1. Role

NASA JSC's Earth Observation Laboratory (EOL) provided essential support for the HERCULES experiment, as well as continuous real-time support during all phases of the STS-56 mission. In fact, the EOL's function encompasses pre-mission planning, mission support, and post-mission analysis of any Shuttle-borne, Earth-looking payload or activity that is

concerned about the influence of atmospheric conditions upon its data collection.[Ref. 19:p. 1]. As previously mentioned, the EOL made cloud-cover assessments on potential imaging sites about which it was queried from the HERCULES Replanning Group. When time permitted, it also provided the shiptrack investigators with real-time satellite imagery support through its access to all of the environmental satellites (except DMSP) listed in Table 1 of Chapter II. Orbital ground tracks are normally displayed over the satellite image in use, to aid in visualizing and specifying areas of interest. Another of the EOL's vital functions was that of producing and providing the most current version of the Orbital Trace Planning Chart, which was one of the primary planning tools used by the HERCULES investigators. During the course of the mission, necessary adjustments to the Shuttle state vector (correction burns) slightly alter the Shuttle's position, which in turn affects its Earth trace. In order to ensure that the most accurate planning information was used, a revised chart was produced after these correction burns were performed.

2. Resources

The Man computer Interactive Data Access System (McIDAS) mainframe at the University of Wisconsin, via the INTERNET communications system, is the main source of real-time data for the EOL. A wide variety of other meteorological data is also available through this system. Phone line

backups, including a GOES-Tap line to the World Weather Building in Washington, D.C., are also in place. Audio and video connections to the various mission support groups at JSC are utilized. Computer information and data exchange is available via INTERNET, OMNET, and SEAN communication systems.[Ref. 19: p.1].

During mission support operations, the EOL conducts global environmental monitoring, providing briefings daily and as needed. When requested, images (normally from environmental satellites) can be uplinked to the Shuttle crew via the Text and Graphics (TAGS) high-resolution facsimile system, or the Thermal Impulse Printer System (TIPS).[Ref. 19:p. 2]. TAGS can only uplink images using the Shuttle Ku-band, whereas the TIPS can operate with either the Ku- or S-band.[Ref. 18:p. 6-4]. This capability offers a potentially useful feature for the shiptrack investigation, in that visual cuing of a developing track or track-formation region can be uplinked to the crew just prior to an orbital pass over the area of interest (provided that the appropriate uplink band and transmit time is available and allocated).

The EOL harbors a versatile image analysis capability, utilizing a Kabuta Pacific Titan 1500 Unix workstation, which includes a graphic expansion board, digitizing table, and a 1K X 1K high resolution 24-bit color display monitor. A variety of image processing software applications, and several other platforms, are available. Digital satellite, digitized film,

and ESC imagery can all be analyzed using these systems.[Ref. 19:p. 2].

C. EXECUTE PACKAGE

One of the primary methods of routinely informing the STS crew of pertinent information affecting the mission (e.g., payload procedural updates, scheduling revisions, various status summaries,etc.) while on orbit is via an uplinked Execute Package. The STS-56 mission, operating with two shifts, received two Execute Packages daily--one for each shift. The lead time required for assembling the Execute Package, and its associated deadline for receiving inputs, was one of the determining factors in the HERCULES target replanning process. An example of a HERCULES Target Update section contained in an Execute Package is provided in Appendix C.

Each Target Update contained essential information, listed under appropriate headings, about the targets requested to be imaged during that particular shift. The headings designated the following information: orbit number, site name, master list identification number, time of closest approach (in Mission Elapsed Time--the standard time reference used by NASA for nearly every aspect of mission operations), expected cross-track angle, Earth coordinates, the requested lens and filter combination, type of shot (e.g., resolution, geolocation,etc), and a reference number to the world

physiological atlas carried onboard. Brief, amplifying notes for each site were also included, as well as a reference number (if any) to the Site Book carried onboard. The Site Book contained detailed chart depictions of previously selected high-interest or high-priority sites to be imaged. The Target Update List provided sites to cover the entire shift, including times when the HERCULES system was not slated for use, in order to accommodate any unexpected scheduling changes.

For some targets, such as predicted shiptrack areas or open ocean sites, blocks of Mission Elapsed Time were specified, in order to cue the HERCULES operator as to when and where to look for possible features. This was necessary due in part to the lead-time constraints on the HERCULES target planning process (discussed below), and to the limitations which arise when using presently observed meteorological conditions and satellite imagery to predict the formation or dissipation of a variable phenomenon such as anomalous cloud tracks. However, the positions of any shiptracks actually observed that coincided with an upcoming orbital pass could be relayed on a more real-time basis, through specific procedures addressed in subsection D below.

D. PROCEDURES UTILIZED

Procedures were established in order to formulate the HERCULES target updates included in the Execute Package. The

wake-up time of the crewmembers was a determining factor in the lead-time required in these processes. Approximately 13 hours prior to crewmember wakeup, an updated state vector was obtained by the SPOM. This new information was incorporated into the Flight Design System (FDS) computer master target list. A revised list of targets (called the MET list), was produced and given to the HERCULES Replanning Group for review. An updated 1:40,000,000-scale Mercator Projection world mission-planning chart for the next 16 orbits, overlaid with orbit number, Earth trace, and 30-second MET intervals, was provided by the EOL to the HERCULES Replanning Group. This chart was a key tool used for evaluating potential sites to be imaged during the upcoming crew shift. Target review consisted of conducting site comparisons, determining site priorities, obtaining a weather review from the EOL, incorporating any new target request inputs, and specifying the information required for the Target Update List discussed above. This process produced the proposed target list.

The proposed list was then provided to the FDS operators for another computer check against any updated state vectors, and the finalized list was created. The Replanning Group then submitted this list to the SPOM no later than eight hours prior to shift wakeup (W-8). The list was subsequently incorporated into the Execute Package by the Flight Activities Officer (FAO) and uplinked to the crew at W-6 hours.

Obviously, these leadtimes were not compatible with the variable nature of the shiptrack formation phenomenon, which may be temporally and spatially irregular. Procedures were established for handling HERCULES "real-time" sites of opportunity (i.e., sites requested after the Execute Package was completed). In these instances, the SPOM again coordinated the process. Upon receipt of a desired real-time target, the SPOM requested visual forecasts and weather satellite imagery of the proposed site from the EOL. Provided the conditions were acceptable for imaging the proposed site, the SPOM then sent a request (via a Flight Note) to the Payloads Officer and Flight Activities Officer at Mission Control Center (MCC) no later than three hours prior to the intended time of imaging (acquisition of signal). The Flight Activities Officer (FAO) then determined if the request would fit into the mission timeline, and coordinated review and approval. If approved, the FAO coordinated the message uplink to the crew, with the requirement that the information be received on board no later than one hour prior to imaging time.[Ref. 20].

The Flight Note procedure allowed an avenue for providing some cuing to the crew in a relatively real-time manner, but the intended target necessarily needed to be of considerable importance, and have an associated high degree of certainty, in order to gain approval through the echelons. Likewise, an investigator can not expect to use this process as a matter of

routine. Therefore, the practice of specifying "MET blocks" in the Execute Package became the standard method of cuing the crew to potential shiptrack formation areas.

IV. OBSERVATIONS/RESULTS

A. OVERVIEW

The STS-56 "Discovery" mission flew from 8-17 April 1993. The flight was extended by one day due to weather considerations at the primary landing site at Kennedy Space Center, Florida. As mentioned in Chapter II, the author provided HERCULES payload support at JSC while the system was in operation.

The data showing the results of the HERCULES experiment (with a Naval applications focus) presented in this chapter were collected from several sources. These included the JSC HERCULES Project Manager's Preliminary Flight Status Report, a NRL HERCULES Postmission Data Analysis Interim Report, and the author's own observations and analysis. Amplifying comments are provided in each section where needed; however, more in-depth discussions and individual cases are presented in Chapter V (Analysis).

B. OBSERVATIONAL DATA

The following table depicts information concerning the time periods allocated for conducting HERCULES observations.

TABLE 5. STS-56 HERCULES Observation Period Data.

(A) HERCULES observation hours scheduled	60.5
(B) Potential shiptrack periods specified in Execute Packages	25
(C) Potential shiptrack periods specified which occurred during scheduled HERCULES observation hours	15
(D) Periods during (C) in which images were obtained	14
(E) Potential shiptrack periods specified in which HERCULES not scheduled, but images obtained	2
(F) Potential periods requested via Flight Note	1

Table 5 illustrates that, as previously mentioned in Chapter III, periods for potential shiptrack observations were specified in the Execute Packages to cover the entire shift, in the event that schedule changes occurred (either additional or less time for HERCULES use). The crew response was overwhelmingly positive. Note in particular that at least one image was obtained during every period specified for potential shiptrack observations, with one exception. However, this exception was due to the necessity of performing an updated HERCULES star alignment at that time; also, a period had been specified, and an image obtained, just 28 minutes prior to this time.

There were two additional periods in which HERCULES images were obtained even though HERCULES observations were not

scheduled. Crewmembers may perform inflight activities during their scheduled mealtimes, and pre- or post-sleep times at their discretion, and such was the case in these instances. During the period requested via Flight Note, a sequence of ten images was obtained--which is indicative of its associated importance and emphasis.

C. IMAGERY DATA

Table 6 depicts specific information concerning the numbers of HERCULES images taken during the STS-56 mission.

TABLE 6. STS-56 HERCULES IMAGERY DATA.

(A)* Total number of images obtained	507
(B)* Images with stars--used for HERCULES alignment	176
(C)* Images with in-cabin shots	15
(D)* Images geolocated by EOL and which have HERCULES information	86
(E)* Images geolocated by EOL with no HERCULES information	20
(F)* Images qualitatively located by EOL (general area description)	23
(G)* Images not geolocatable by EOL (unidentifiable land shots, potential ship wakes, clouds, moon shots, etc.)	187
(H) <u>Earth-looking</u> shots with HERCULES coordinates, but due to lack of identifiable feature, could not be geolocated by EOL	81
(I) Number of (H) which were of usable quality (i.e.,not blank, black, or blurred)	56
(J) Earth-looking shots without either HERCULES coordinates or geolocatable by EOL	61
(K) Number of (J) which were of usable quality	46

*<u>Note</u>: Rows (A) through (G) from [Ref 21].

Table 6 illustrates the potential value of the HERCULES system in imaging open-ocean areas or regions of few identifiable land features. In a separate preliminary analysis conducted by the JSC Electronic Still Camera Laboratory, it was noted that 86 images contained HERCULES information and were geolocatable, whereas 20 contained no HERCULES information, but were geolocatable by the EOL using postmission reconstruction techniques. The procedure essentially utilizes the known MET when the image was taken (and the corresponding Shuttle nadir position and altitude) to calculate the center position of the image (drawing on recognizable features within the image). This is currently done for all film-based Shuttle imagery as well--a time-consuming process, considering the hundreds of photographs taken during each mission. Another 23 images were "qualitatively" located by EOL (exact location not confirmed, but general area described) [Ref. 21].

Without the HERCULES system, the location of the images counted in rows (H) and (I) would be otherwise unknown. The majority of the 61 images noted in row (J) did not have HERCULES coordinates due to a temporary system fault (later rectified in-flight). This number also does not include an additional 49 images taken with the ESC only, after the HERCULES locating system was secured (since no further state vector updates were received) on the extended flight day.

D. NAVAL APPLICATIONS IMAGERY DATA

Tables 7 and 8 provide information concerning the Naval applications imagery taken during the STS-56 mission:

TABLE 7. STS-56 HERCULES NAVAL APPLICATIONS IMAGERY DATA.

(A) Shiptrack Investigation Images taken	46
(B) "Naval" sites (ports, harbors,etc.) requested	41
(C) Number of (C) which were repeat requests	8
(D) Adjusted number of (B)	33
(E) Images taken of requested "Naval" sites	17
(F) Additional "Naval" sites taken	9
(G) Other ocean sites (reefs,vegetation,etc,) taken	12
TOTAL (A,E,F,G)	84

The 46 shiptrack investigation images noted in Table 7 were taken during the 18 periods specified in Table 5. There were 41 requests made (via the execute packages) for specific Naval-related sites to be imaged. These sites were either for testing the HERCULES system's geolocation accuracy and capability of resolving any ships in the vicinity (e.g., in harbors, along coasts), or had some other requestor-specific purpose. (Eight of these were repeats, so the adjusted total was 33). Images were obtained for 17 of these requests; the remainder were most likely not imaged due to a number of factors, including weather or haze obscuration, difficulty in locating the target, time considerations, etc. However, nine other alternate sites were imaged. The 12 other ocean sites were primarily ocean vegetation images taken to test the H9 filter.

TABLE 8. LENS/FILTER COMBINATIONS (NUMBER of IMAGES) for NAVAL-RELATED SITES.

LENS	FILTER				
	H3	H4	H9	NONE	OTHER
50mm	2	11	5	0	0
180mm	2	17	4	5	0
300mm		13		9	0
2 x 300 (600mm)		0		7	0
Image Intnsfr				6	

Notes: (a) None taken with 1000mm or 1.4 x 300 (420mm).
(b) 3 taken with unknown combinations.

Table 8 illustrates the various lens/filter combinations used for the Naval applications shots. Shaded areas indicate combinations that are not possible. The "Other" filter category includes the polarizing, Wratten-12, and IR-cutoff filters carried on the mission. While none of these filters, or the lenses specified in note (a), were used on Naval applications sites, they were tested with other locations and situations during the flight.

One subjective observation, after the author's review of over 100 HERCULES images, is that the 180mm lens with no filter attached produced the "best-quality" images. Specifically, these images had sharper contrast, were clearer, and had better exposure quality, while providing the optimum mix of resolution and field of view. Most of the images taken with the H4 filter were so dark that distinct features were

evident only when enhancement techniques (histogram, linear mapping) were employed. Any contrast advantages anticipated with the filter's use on overwater cloud shots were counteracted by the loss in transmissibility experienced (hence the dark images). Likewise, no apparent advantage was seen in images taken with the H3 filter. Images taken with the H9 filter, used for ocean vegetation shots, were also very dark and required enhancement techniques in order to see any distinctive features.

E. DOWNLINK/DISSEMINATION DATA

Downlink and dissemination of HERCULES imagery was conducted during the mission. Table 9 provides information on these procedures.

TABLE 9. STS-56 IMAGE DOWNLINK/DISSEMINATION DATA.

Total Downlink Periods	13
"Unscheduled" Downlink Periods	1
Images Downlinked	118
"Unscheduled" Images Downlinked	2
Images disseminated to, and received by, Fleet Units	13

The STS-56 Flight Plan originally called for four scheduled downlink periods, each of which included 20 minutes for crewmember image review and selection, and 35 minutes for image transmission. This was subsequently modified to 13 periods of varying amounts of time, in order to accommodate the adjusted requirements of the ATLAS-2 primary payload, which experienced some internal downlink equipment

difficulties. As a result, the HERCULES experiment actually gained additional total downlink time.

The "unscheduled" downlink involved the following sequence of events: 1) crew was notified of the allocated Ku-band and the MET for when the downlink was to be performed, 2) sites of opportunity were selected and imaged by crewmember just prior to this time, 3) images were immediately downlinked from "Discovery" to the HERCULES ESC payload support team at JSC, 4) ESC team disseminated imagery to selected remote sites as quickly as possible after receipt.

A five-minute time window was allocated for performing the "unscheduled" downlink, which was sufficient for transmitting two images. It took approximately 30 seconds after the images were received at JSC to process them for dissemination. Thereafter, the time required for receipt of the images at a remote site was a function of the method utilized to receive them. For example, transmission to one remote user, Jet Propulsion Laboratory (JPL) in Pasadena, California, required only 15 seconds, since it had a direct line tie-in to the ESC support room. Dissemination from JSC to Fleet users occurred within 15 minutes of image reception at the ESC support room.

Post-mission feedback also indicates that a total of six images were received aboard the USS "Guam" over a 94 minute period. These were transmitted from the Atlantic Intelligence Center (AIC) utilizing the Fleet broadcast 2.4 KB UHF channel, and compression techniques which reduced image size to 512K x

512K. Median transmission time per image from JSC to AIC was 22 minutes, while the median transmission time from AIC to Fleet broadcast (received by USS "Guam") per image was nine minutes [Ref. 22]. JICPAC reported that a total of 13 images were received from JSC during the period of 12-14 April, with an average transmission time per image of 25 minutes. The method of transmission was not reported.[Ref 23].

F. PROCEDURAL OBSERVATIONS

Several procedural items were noted which deserve mention, as they are particularly pertinent to the MAST experiment manifested for future Shuttle missions.

1. Ship Coordination

a. NOAA Vessels

Position reports on 12 NOAA vessels were regularly received for the duration of the mission from both PMC and AMC. However, maintaining a current, useful plot of all of the ships was a difficult task, due to three factors: 1) lack of a continuously-updated computer display of the ship positions overlaid with Shuttle orbital ground trace, 2) the reports did not contain the ship's present or intended course/speed, 3) time delays in receiving the reports at JSC rendered the information essentially useless for real-time planning purposes. In particular, positional information on weekend days was not received until the following Monday.

However, these drawbacks did not result in a completely wasted effort. Since only a few of the vessels were operating in regions conducive to shiptrack formation, concentration was focused on four of the vessels: "Discoverer", "David Starr Jordan", " Surveyor", and "Malcolm Baldridge". Of these, the "Discoverer", enroute from Hawaii to Seattle, and the "David Starr Jordan", operating near the Channel Islands off of the Southern California coast, were considered primary candidates for either potential shiptrack formation or for a direct image of the ship itself. A potential rendezvous situation with "Discovery" overflying "Discoverer" emerged for orbit 102, and both crews were duly notified. A more detailed description and analysis of this case is found in Chapter V. The cooperation received from both PMC and AMC was excellent. PMC responded rapidly to real-time requests for data collection by utilizing the INMARSAT telephone link to communicate with NOAA ships "Discoverer" and "Surveyor".

b. U.S. Navy Vessels

As discussed in Chapter II, positional information on U.S. Navy vessels was provided via secure (STU-III) telephone link to the 24-hour watch team at NAVSPASUR, Dahlgren, Virginia. This process, while providing some useful information, proved cumbersome due to the inevitable time delays experienced, and number of separate calls required, for

each update. This method required the author to: determine areas conducive to potential shiptrack formation, relay these areas to the watch team, then wait while the JOTS operator compiled the requested positional information on the five largest Navy vessels in these areas. The watch team then called back with the positional information. The author next compared this with the available weather satellite depictions to determine the potential for obtaining an image of either a shiptrack or the ship itself. However, the utility of this information was limited by the recency of the update received on the JOTS terminal. Also, since knowledge of the ships' intended movements was not known, construction of projected positional plots was not possible. An on-site JOTS terminal, with information immediately available (and visible) to the user, is essential to the proper utilization of this source of data.

The procedure actually yielded one unique MAST case (currently undergoing further analysis at the Naval Postgraduate School), in which four Navy vessels with different power plants were transiting in formation and producing shiptracks. The tracks were observed in NOAA-11/12 satellite imagery. Unfortunately, the Shuttle's orbital path placed it too far from the area to allow any coincident imagery to be taken.

A concentrated effort was also undertaken in an attempt to vector an aircraft carrier battlegroup into a

designated turn at a specified time (MET) during "Discovery's" overflight. The intent was to create an associated water wake of sufficient size and contrast to be visible (and photographable) from orbit. The designated MET and viewing area were relayed via the Execute Package; however, this opportunity was subsequently canceled due to a change in the battlegroup's tasking orders.

The above examples illustrate some of the types of difficulties which were (and will be) encountered when attempting to gather data or conduct a *field* study by utilizing operational assets on a "non-dedicated" or "as available" basis. Despite these drawbacks, valuable experience was gained for the future dedicated MAST payload.

2. Satellite Imagery

a. Availability

As mentioned in Chapter II, weather satellite imagery support for the HERCULES experiment (including the shiptrack investigation study) was provided through the facilities at the Earth Observation Laboratory (EOL)at JSC. The support received from the EOL was excellent, with assistance for the shiptrack investigation provided to the maximum extent possible, given the time and resources (personnel and computer) available. However, it became evident that this type of investigation required almost full-time access to the various weather satellite imagery and

world-wide weather outlook products. The EOL could not back an (essentially "ad hoc") effort of this scale without interfering with its numerous other planned mission support requirements. (Given sufficient planning time and resources, the necessary support can be readily provided--and such is the case with the actual MAST payload scheduled for 1994).

b. Geostationary Imagery

Imagery from the geostationary weather satellites (GOES, GMS, METEOSAT) was the most readily available source of cuing for potential shiptrack features. "Zoom-ins" of potential areas were viewed in both visible and IR channels. Resolutions of 4 nmi and 8 nmi, respectively, were typically used for GOES images. Shuttle orbital tracks with MET tic-marks were overlaid on the views to help determine appropriate areas to be specified in the Execute Packages. One difficulty with using the geostationary satellite visible images was that the desired region was sometimes still in darkness.

c. NOAA Imagery

Because of its higher resolution, NOAA AVHRR imagery of areas which looked particularly promising for shiptrack development was viewed whenever possible. However, access to this imagery was usually very limited, due to the EOL time and resource considerations mentioned above. As was previously pointed out, the difficulty with this procedure was that the lead time required for making an Execute Package

input necessitated viewing the imagery some 12 to 18 hours prior to "Discovery"'s actual overflight of any potential areas of shiptrack formation. Another problem was that when time did permit accessing AVHRR imagery, the most recent image of the desired area might itself be several hours old, or have an oblique view angle.

d. DMSP Imagery

Arrangements for recurring use of DMSP satellite imagery were not pursued prior to the mission. However, a request was made during the mission to the Fleet Numerical Oceanographic Center (FNOC), Monterey, California for recording visible and IR channels on DMSP passes covering the Eastern Pacific region between the U.S. West Coast and Hawaii for four separate time periods covering 12-13 April ("Discovery" orbits 71, 72, 87, 88). The requested information was recorded, and hard-copy composite images were made. However, these products were of very limited use due to their recorded resolution (5.2 nmi). A higher resolution can be recorded, but this requires prior planning. Since DMSP satellites have encrypted downlink, their information is not normally available at JSC's EOL. Also, in order to obtain coverage of specific regions over the world, a DMSP receiver must either be located within the region to receive the downlink (such as at FNOC Monterey), or else a pre-arranged "record-store-dump" to another receiver site procedure must

be scheduled. Careful consideration should be given to the proper employment of DMSP satellite capability for the 1994 MAST payload.

3. Potential NASA ER-2 Underflight

An opportunity for a potential underflight of a NASA Ames ER-2 high-altitude research flight, outfitted with its own CCD camera and other sensors, emerged during the mission. "Discovery"'s original orbit 102 on 14 April placed it some 150 nmi west of the San Francisco, California coast, near the Ames ER-2 base. The Ames High-Altitude Research Branch was provided with the appropriate information. As mentioned in Chapter II, pre-mission discussions revealed that there was a possibility of scheduling a one-two hour "maintenance-check" flight off the central California coast sometime during the mission, in which the CCD camera could be utilized. Such a flight would provide imagery comparisons between the two CCD systems and also provide a means of "ground truth" verification of any over-water HERCULES shots taken of the coincident area.

However, updated Shuttle ephemeris shifted the ground trace 360nmi eastward over the continent . Also, since the CCD camera system had only recently returned from the TOGA-CORE research study in the Pacific, it was unavailable for outfitting. Likewise, the ER-2 was unavailable for flight at the time, so the effort was not further pursued.

4. Orbit 71 West Coast Pass

An orbital pass along the western coast of the U.S. occurred on 12 April from 1525-1529Z during orbit 71. This particular pass was significant because the crew positioned one of "Discovery"'s Payload Bay video cameras into an Earth-looking view and transmitted live video imagery of the flyby. Along with some outstanding clear-area views of the California coast (including the San Francisco and Monterey Bay areas), numerous linear cloud features were also visible to the north and south of this region. Some were obviously aircraft contrails and high cirrus cloud streaks, but others had shiptrack-type qualities. The camera was "zoomed-in" several times in the vicinity of these features. A videotape record of this pass was obtained from NASA JSC and reviewed by the author for potential shiptrack investigation study.

The video footage provides the viewer with an excellent sense of the Shuttle's rate of passage over a given region. However, no attempt was made to correlate any of the track-like features briefly seen in the video with actual ships, since such an effort would have little likelihood of success and would essentially add no new information to the study's body of knowledge. This case does exemplify the utility and versatility of having an astronaut "in the loop" for the type of scientific investigation (such as the shiptrack study) which can benefit from an on-scene person's ability to respond to changing conditions.

CHAPTER V. ANALYSIS

A. OVERVIEW

This chapter presents the analysis of several cases and provides illustrative examples of imagery taken during the STS-56 mission, and amplifies some specific points brought out in earlier discussion. Howard and Garriott [Ref. 24] provide an informative discussion and theoretical calculations regarding the imaging of ships and ship-related features by astronauts using hand-held cameras (including CCD cameras). The logic followed in their discussion is extended here to the application of imaging potential cloud shiptrack features.

B. ANALYSIS PROCEDURES

After the mission, the STS-56 HERCULES imagery files were made available to the author via File Transfer Protocol (FTP) from the ESC Laboratory at JSC. The files were initially viewed on the VAX/VMS computer system located at the Naval Postgraduate School Meteorology Department's Interactive Digital Environmental Analysis (IDEA) Laboratory. Primary focus was placed on those images related to the shiptrack investigation study and Naval applications. Copies of the crew's HERCULES Camera Data logs, tapes of the post-mission HERCULES Debriefing Conference, the ESC Laboratory's HERCULES Image Document files and the HERCULES Project Manager's STS-56

Postflight Status Report were utilized to assist in the analysis.

The HERCULES Camera Data Logs contain the astronaut's written annotations of the lens and filter combination, target, and exposure configuration, along with any pertinent comments, for each image taken with the HERCULES system. The ESC Image Document files contain the same information, along with the HERCULES-computed center position, GMT, and MET. The Postflight Status Report provides tabular listings of the above information, plus additional useful information such as the orbit number, nadir position of the Shuttle, the EOL computed position of the image, the ground spatial distance (pixel size at image center), and a brief comment about the location or quality of each image.

Potential shiptrack images were initially scanned for any linear cloud-type features (i.e., anything that "looked like" a shiptrack) within the frame. If any such features were present, a histogram enhancement operation was used in order to make the features "stand out". Eventually, employment of the histogram technique became standard procedure for all images viewed, since in many cases (especially those taken with the H4 filter), the images were so dark that this was the only way in which any features could be clearly distinguished. The other Naval applications images were scanned in a similar manner, with a focus toward finding any vessels underway or in port, and in locating any water wake or other distinctive

features around ports or harbors (e.g., river runoff effluent, wave patterns, etc.).

"Promising" images were next compared to any weather satellite imagery obtained of the same area and time, in order to gain an overall view of the region, and to correlate any notable features of interest. A Shuttle "Groundtrack Time to Position" listing (supplied by the EOL), along with the Program Manager's Postflight Status Report, provided cross references for any HERCULES time and positional information that was obtained with the images. In several cases, no corresponding satellite imagery hardcopy record was available for immediate comparison, so archived AVHRR imagery of the most promising areas was obtained through sources such as the NPS Oceanography Department and NRL Monterey, or ordered through NOAA Environmental Satellite Data and Information Service, Camp Springs, Maryland.

A group of 25 images from a "first-cut" list of 80 was then selected for processing in full-frame view on a SUN Sparc 2 workstation. This station provides a full complement of image processing and display applications, including enhancement, enlargement, and measurement tools. The representative cases discussed below were selected from this group. In addition, weather and positional information from three NOAA vessels ("Discoverer","David Starr Jordan", and "Malcolm Baldridge"), which had operated in areas deemed to be of the highest shiptrack-forming potential, was obtained for

post-mission reconstruction purposes, in anticipation of correlation with HERCULES imagery.

Of the following cases, only one depicts an image containing a feature that is "highly likely" to be a shiptrack in clouds. It is, in fact, the only image (of the 46 potential shiptrack images taken during the mission) that was given this designation. However, it should be remembered that <u>number</u> of images containing the desired feature is not the sole criterion for determining HERCULES system's potential in this type of application. Instead, this decision must be based upon an assessment of the system's <u>overall</u> capabilities. The following examples serve to illustrate this approach.

C. ILLUSTRATIVE CASES AND EXAMPLES

Individual HERCULES images are referred to (in this study) by the "ESC" designation followed by the disk and respective "frame" number within the disk, listed as one complete number. For example, "ESC 10039" indicates the HERCULES ESC image located on disk 10, frame 39. The NASA JSC designation also contains a mission reference number, such as "STS056-". Although images which contain HERCULES geolocation and time information can be printed with this data displayed in a designated area beyond the right border of the image, the figures used here do not show this information due to sizing and processing considerations. This data, along with additional information, is listed within the text instead.

Pixel counts were used to measure distances of particular features of interest found on the images. The number of pixels is converted to a linear distance by multiplying by the Ground Spatial Distance (GSD), also called Ground Resolution, or pixel size at nadir, for a particular image. Calculation of GSD (Ground Resolution) was described in Chapter II. Actually, each pixel has both a vertical (Y) and horizontal (X) size. The Y resolution is the vertical size of the pixels in the image, while the X resolution is the horizontal size of the pixels in the center row in the image [Ref. 21]. In essence, the horizontal pixel size represents a longer ground measure as the distance from the image center increases. Expressions for these calculations, developed by Dr. Sandeep Jaggi of the NASA JSC ESC Laboratory, are found in Appendix D. For simplicity, the measurements made in these analyses were performed assuming a uniform pixel size throughout the particular image, and also that the image is a nadir shot (zero azimuth from Shuttle centerline). The figures mentioned in each case are found immediately following the discussion (subsection) pertaining to that particular case.

1. ESC 10039

This case contains a linear feature which is "highly likely" to be a shiptrack in clouds. Data parameters are:

Table 10. ESC 10039 DATA.

DATE	GMT	MET	LAT	LONG	ELEV	ORBIT	LENS	FILTER	GSD
13APR93	103/22:05:46	05/16:36:45	56.5S	123.6W	160nmi	91	50mm	NONE	89.7m

Figure 4 provides the METEOSAT depiction, with superimposed Shuttle ground trace, of the region and time corresponding to this image. Aside from a possible developing stratus layer in the area of interest, no distinguishing shiptrack characteristics can be seen from this satellite view. An enhanced HERCULES image is shown in Figure 5, with the boxed area identifying the feature of interest. With a GSD of 89.7m, the ground field of view presented by this image is 49 x 49 nmi. The linear feature measures 80.63 pixels in length, which equates to 7232.5 meters (3.95nmi). Its width is 4.3 pixels (385.7meters).

This feature appears as part of the lower-lying cloud layer, which distinguishes it from higher cirrus cloud streaks. Also, its edges are more distinct and narrower than those expected of a "natural" cloud formation, including cirrus clouds. An AVHRR image of the same area cannot sufficiently distinguish a feature of these dimensions, and lacks the resolution capability to see whether or not a ship has produced it. While a ship or shiptrack head cannot actually be distinguished in this image, a similar shot taken with a higher-power lens (e.g., 180mm) <u>can</u> provide such information, as is discussed below. This poses the question of determining the point at which the resolution capability of hand-held imagery begins to supplant the limitations of satellite-based imagery in terms of shiptrack investigation.

In answering this question, it is helpful to consider what happens on a "pixel-scale level" in an image. Figure 6 depicts the feature enlarged to 4 times normal, so that individual pixels can be seen. The shiptrack formation process causes an increase in reflectance properties of the overlying cloud layer, which makes the corresponding pixels "brighter" than those of the surrounding area. Although only a portion of the associated pixel might experience this increase in brightness, the entire pixel will be "affected", and thus register a brighter value. Consequently, a linear feature (such as a shiptrack) can "stand out" from the background.

Figure 4: 13 1700Z April 93 METEOSAT Depiction.

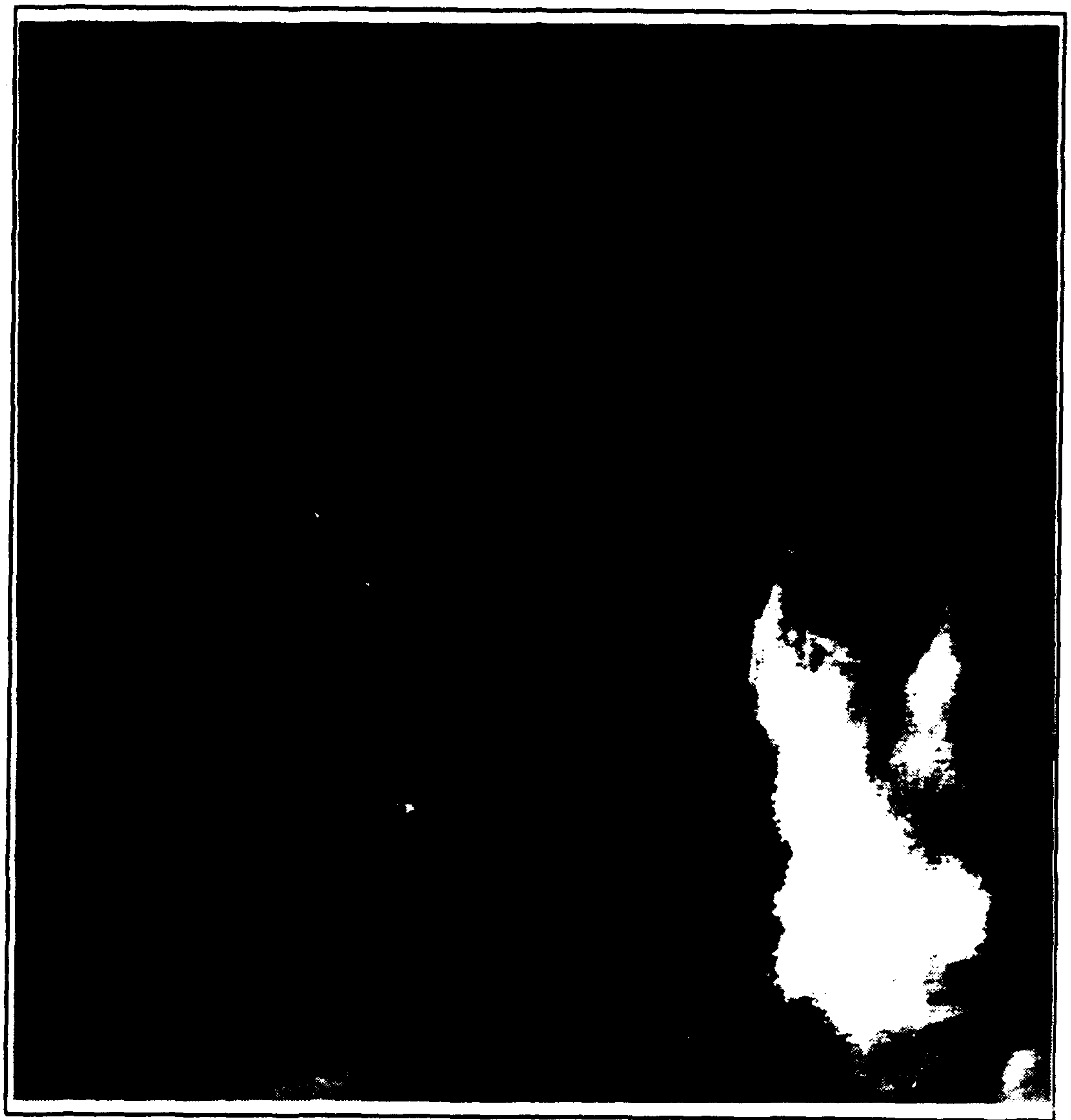


Figure 5: ESC 10039 Enhanced View.

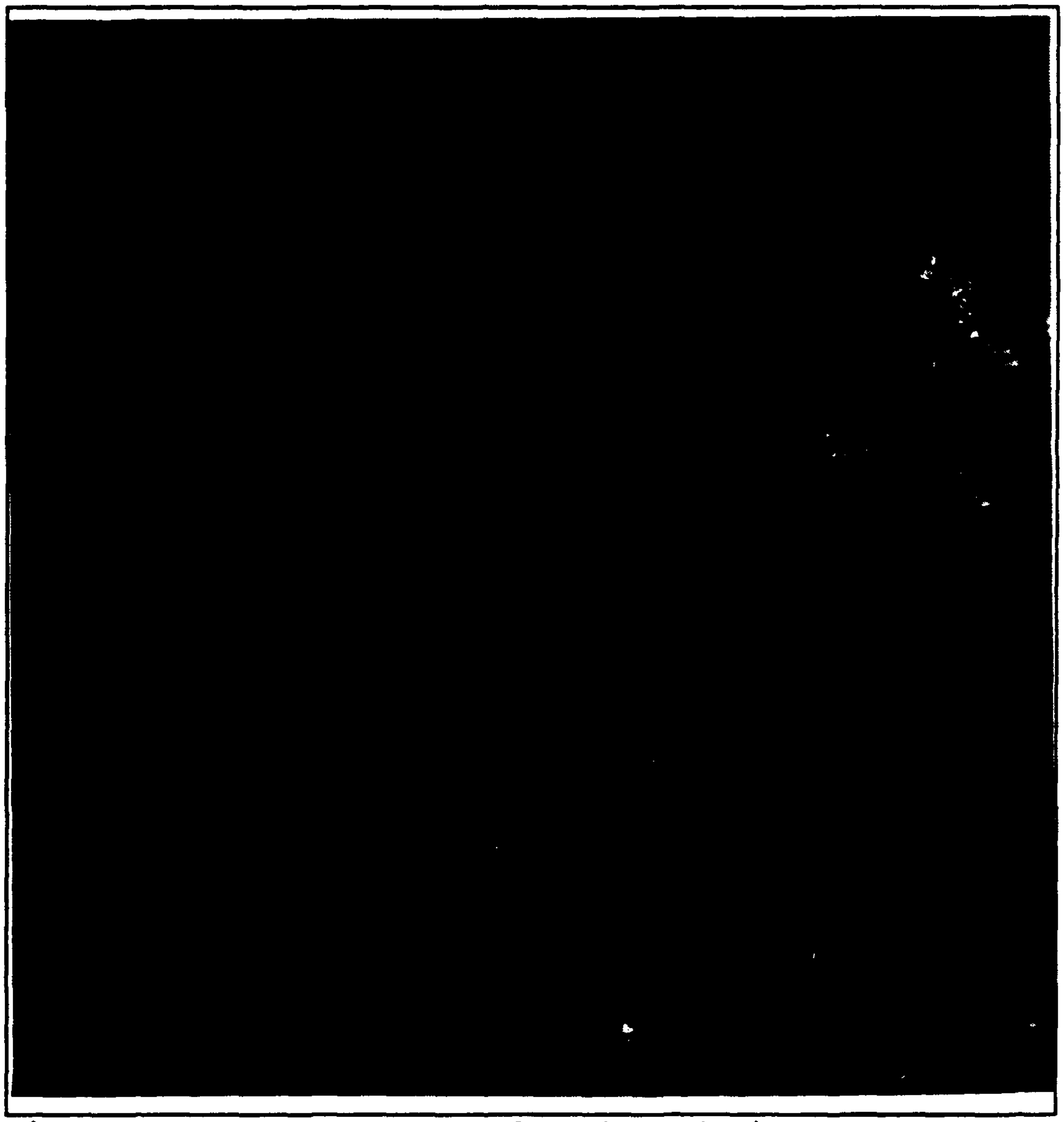


Figure 6: ESC 10039 Enhanced, Enlarged View.

2. ESC 01017

This case presents aspects of linear features detected on the ocean surface which are likely ship water wakes. Since these features are similar in several respects to cloud tracks (linearity, dimensions of length and width), this case exemplifies the type of detection and resolution capabilities possible with the HERCULES system in such an application. Table 11 provides the data parameters:

TABLE 11. ESC 01017 DATA.

DATE	GMT	MET	LAT	LONG	ELEV	ORBIT	LENS	FILTER	GSD
09APR93	099/22:44:24	01/17:15:23	21.7N	156.8W	159nmi	28	300mm	H4	14.9m

Figure 7 shows an enhanced version of this image. The ground field of view is 8 nmi x 8 nmi. Three distinct dark linear features are visible in the image. The crewmember's notation on the HERCULES Camera Data card indicates the image is of a possible ship wake (in this case a water wake), reinforcing the notion that the features are "man-made". The image is admittedly blurred, which underscores the difficulty which can occur in attempting to achieve good-quality hand-held imagery with higher-power lenses. However, the information contained in the image is still of sufficient quality to be usable.

The longest dark line measures 684 pixels, which equates to 10,192m (5.5nmi). It is 27 pixels wide (397m). The shorter dark line which appears to merge with the long line measures 295 pixels in length by 14 pixels wide (4396m =

2.4nmi and 209m, respectively). A "bullet-shaped" bright object seems to line up exactly with the longest dark line, giving the initial impression of an actual ship in a shipping lane. However, measurements reveal that it is 52 pixels (775m) long--too large to be a ship. Instead, it is most likely a cloud. Cloud shadows visible on the surrounding surface reinforce this interpretation. Had these features been atmospheric exhaust wakes instead of water wakes, similar measurements could have been taken (and caution exercised) in interpreting the image.

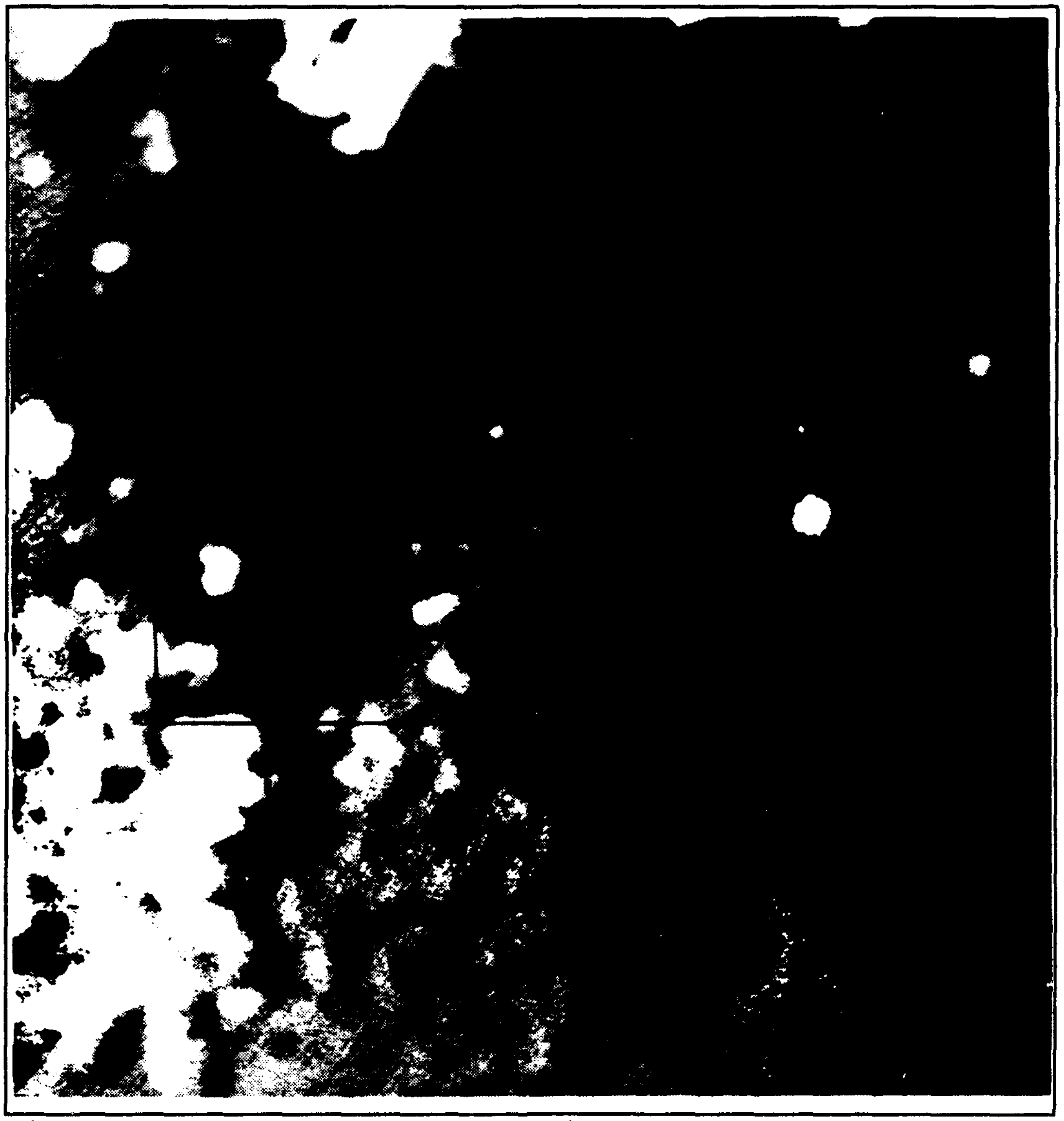


Figure 7: ESC 01017 Enhanced View.

3. ESC 06023

Figures 8 and 9 show the port city of Karlya, Japan, illustrating the type of quality possible with the HERCULES ESC. They feature excellent contrast and high definition. Numerous ships and their associated water wakes are visible in the harbor approaches. Data parameters are listed in Table 12.

TABLE 12. ESC 06023 DATA.

DATE	GMT	MET	LAT	LONG	ELEV	ORBIT	LENS	FILTER	GSD
10APR93	100/22:46:05	02/17:17:04	34.9N	136.9E	158nmi	44	180mm	NONE	24.6m

An enlarged, enhanced view of the boxed region (Figure 10) reveals data on the sizes of the ships visible in the port approaches. Four ships can be distinguished, with pixel counts and computed lengths as follows:

- Ship A: 6.02 pixels = 148m
- Ship B: 6.09 pixels = 150m
- Ship C: 4.50 pixels = 111m; wake is 3.02 pixels = 74m
- Ship D: 5.20 pixels = 128m

This enlarged view also shows the distinctive difference in brightness that those pixels "containing" the ship have, as compared with those of the surrounding water. Similar contrasts would be expected, and measurements made, if the image contained shiptrack cloud lines. Streaks of sedimentary effluent from the channels which empty into the port are visible as well. Again a parallel can be drawn between the type of length/width measurements which can be made of these features and those of potential shiptrack lines.

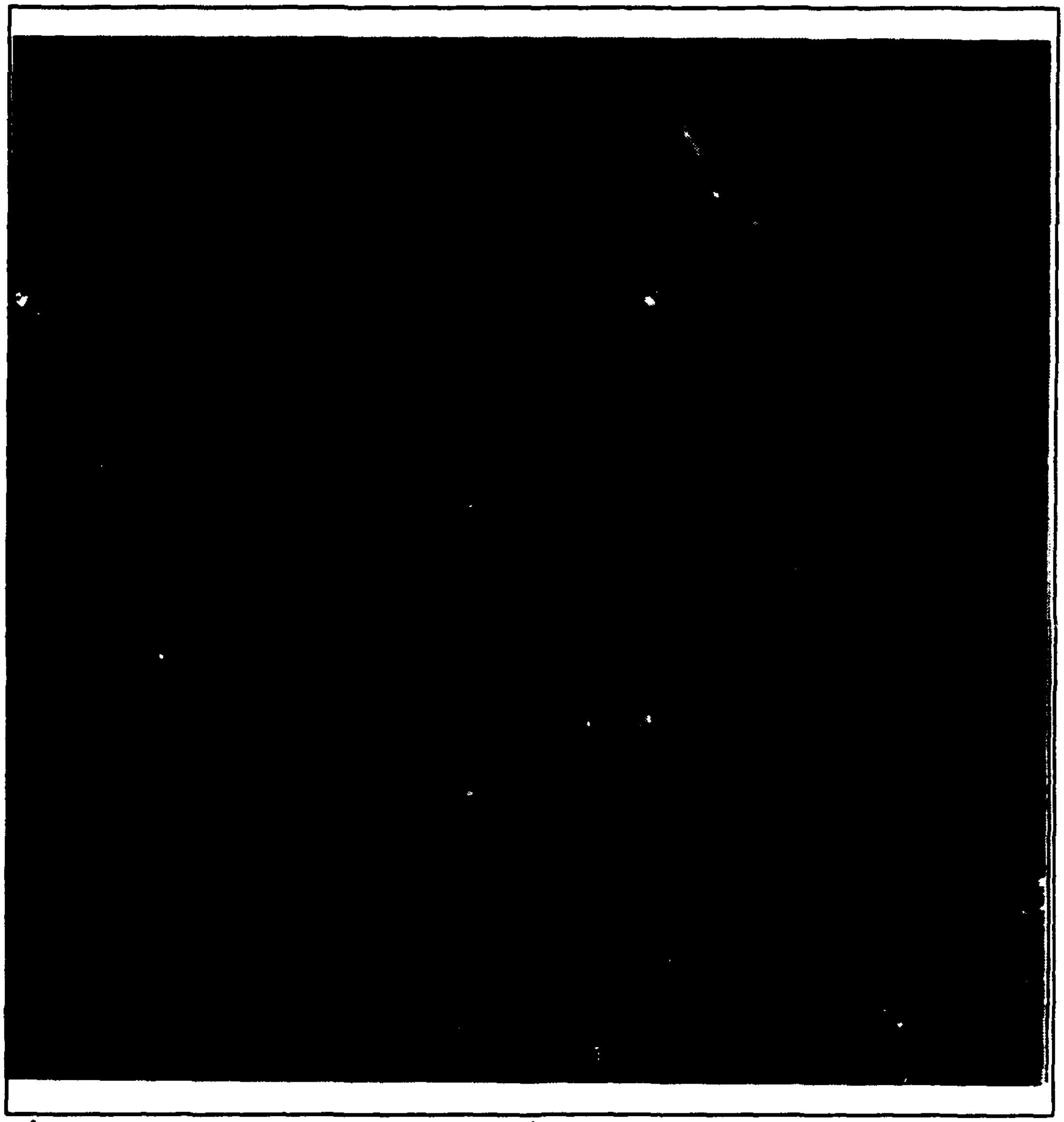


Figure 8: ESC 06023 Normal View. Karlya, Japan.

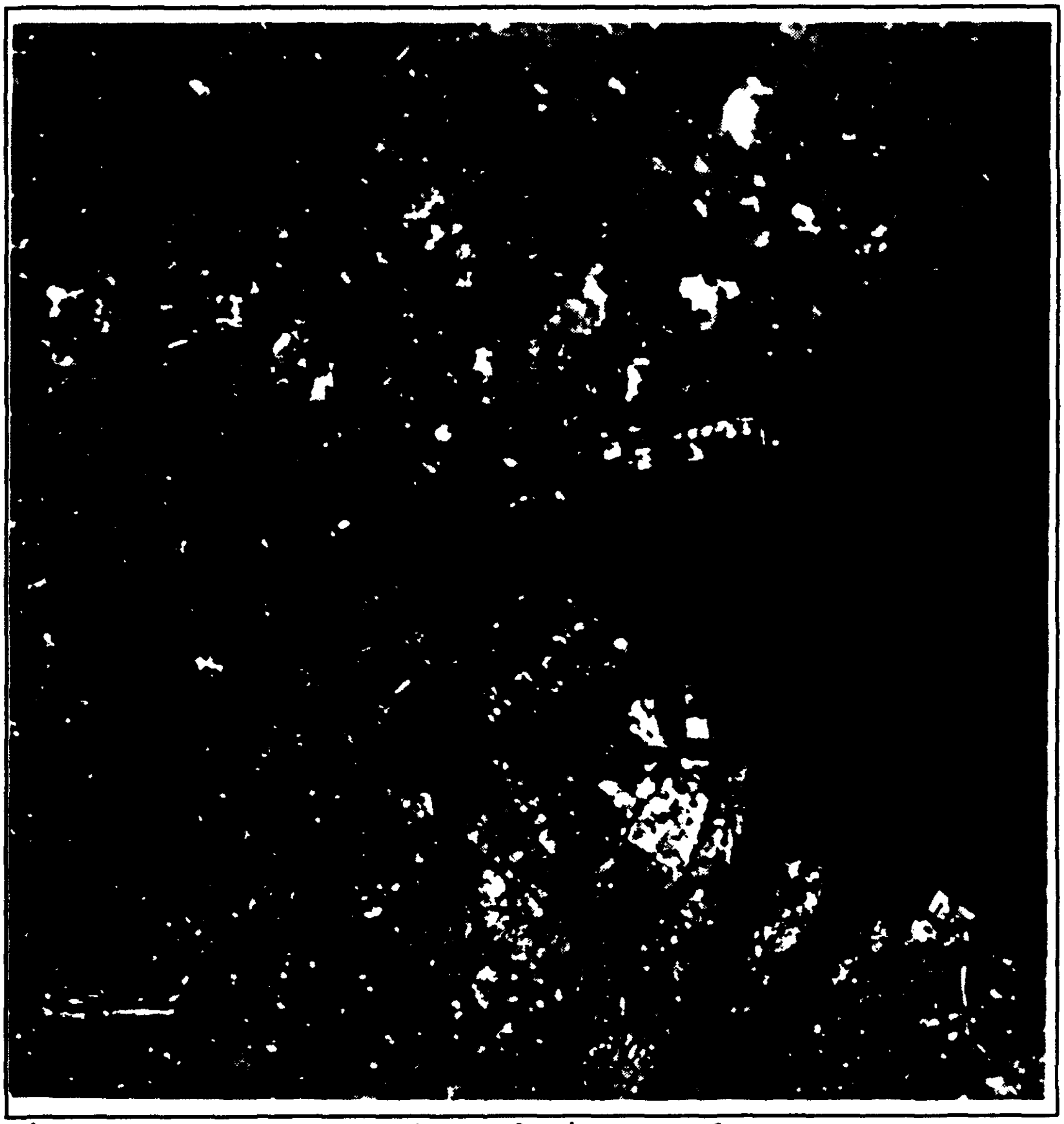


Figure 9: ESC 06023 Enhanced View. Karlya, Japan.

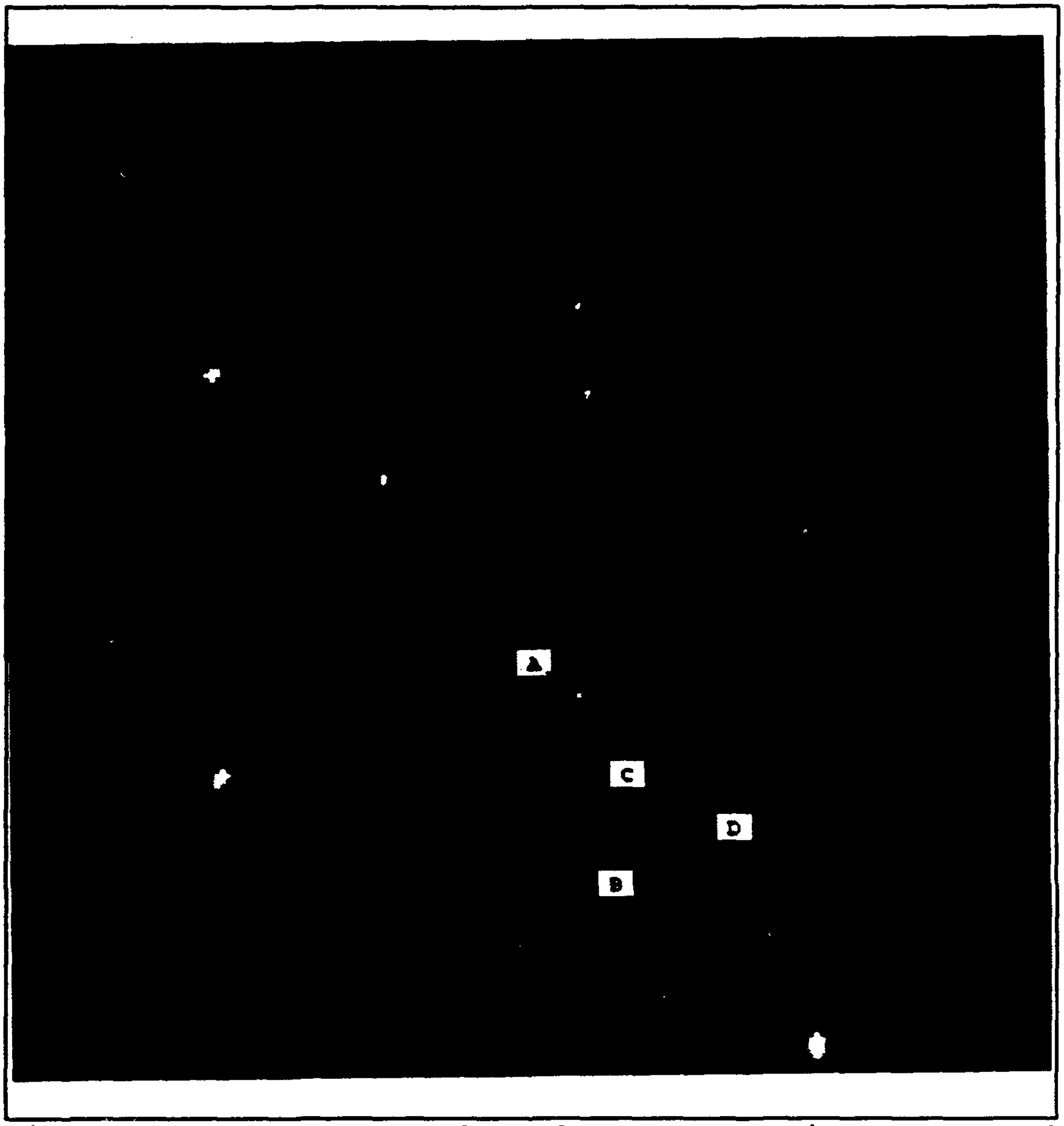


Figure 10: ESC 06023 Enlarged, Enhanced View of Framed Area.

4. ESC 13017

This is an image of shipping traffic in the Straits of Gibraltar. Figure 11 is an enhanced view, while Figure 12 shows an enlarged view of the framed area. Data parameters are listed in Table 13.

TABLE 13. ESC 13017 DATA.

DATE	GMT	MET	LAT	LONG	ELEV	ORBIT	LENS	FILTER	GSD
15APR93	105/06:42:52	07/01:13:52	35.9N	005.6W	158nmi	113	300mm	NONE	14.8m

These views illustrate the capability of the HERCULES system to determine the precise location of a vessel underway, while also showing the potential that the ESC, when outfitted with a 300mm lens, has in discerning a feature's dimensions. The ship located inside the boxed region measures 25.28 pixels (374.1m) long by 3.53 pixels (52.2m) wide. In figure 12, it is just possible to distinguish the dark outline of the ship's hull contrasted within the brighter bow and side wakes, which extend out some 33.5 meters to either side. Near the stern of the vessel, a brighter "block" is visible, which measures 2.4 pixels (35.5m) wide. This is most likely the ship's "blockhouse", or superstructure. Astern of the ship a visible water wake is present, with the brightest portion measuring 15.3 pixels (226.4m). These dimensions are consistent with those of a supertanker underway.

From the HERCULES-generated exact coordinates of the image centerpoint, the corresponding exact coordinates of the vessel can be determined, by simply measuring the horizontal

and vertical distance from this centerpoint. The vessel is located at position 35.89N, 005.65W. This position, coupled with the known precise time that the image was taken (along with the constrained, well-monitored environment offered by the Straits), facilitates determining the ship's name. Merchant shipping databases can be searched to identify what ship correlates to this time and position. Likewise, propulsion plant and other design characteristics would then become known.

From this example, the extension of this capability to the investigation of shiptracks in clouds can be realized. If the ship in this image was in fact generating cloud tracks, the associated dimensional, power plant, and performance characteristics could be readily determined.

Figure 11: ESC 13017 Enhanced View.

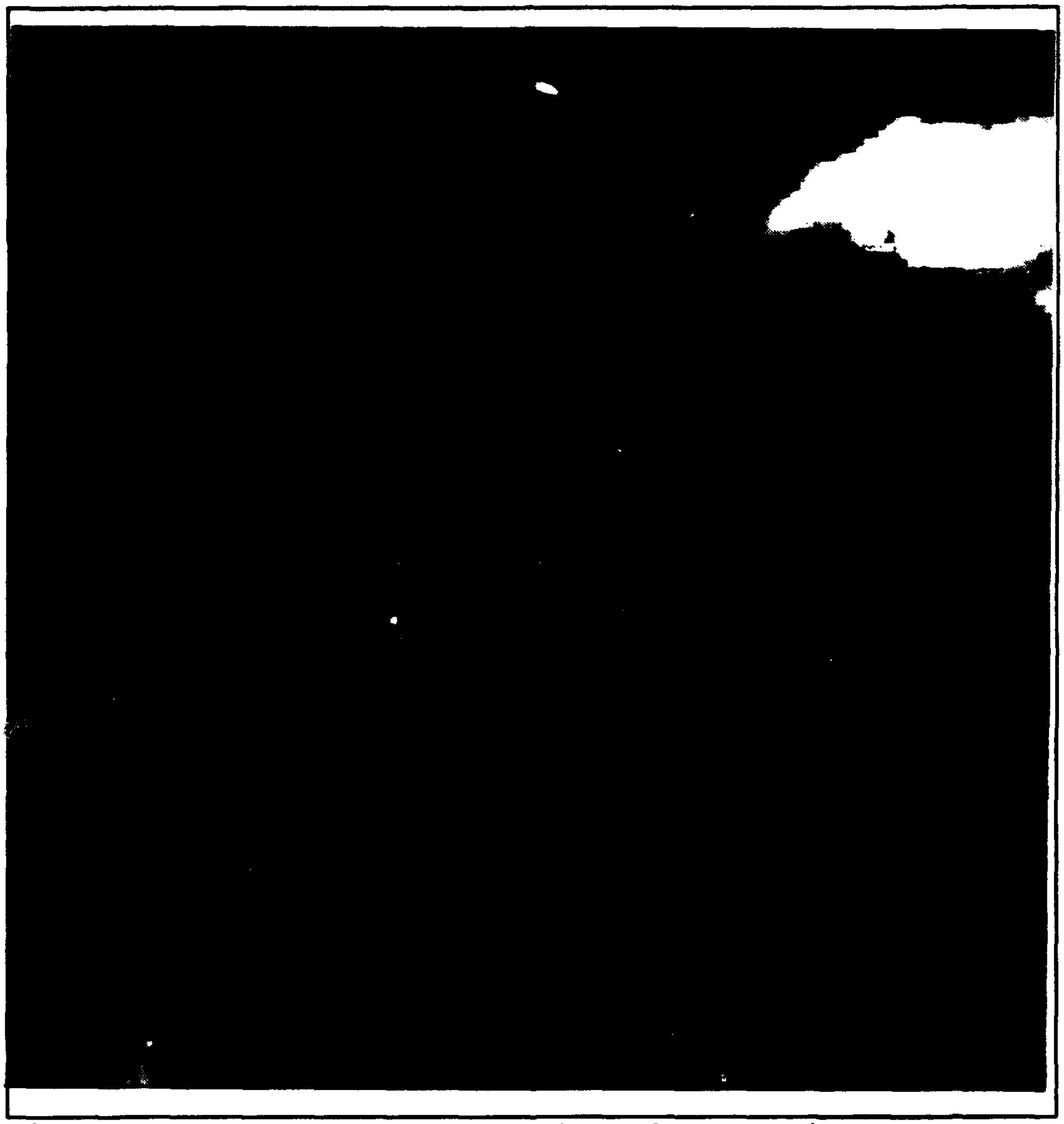


Figure 12: ESC 13017 Enhanced, Enlarged View of Framed Area.

5. Additional Examples

The following examples illustrate imagery taken during "blocks" of MET specified for the purpose of shiptrack investigation. In these instances, imagery was usually either taken of any "track-like" feature the astronaut observed, or a sequence of images was taken along the track during the specified time. When available, corresponding satellite imagery was reviewed for possible correlation with the images.

a. *ESC 11024, ESC 11025, ESC 11028*

These images are representative of a sequence of nine taken during orbit 95 on 14 April off of the southwest coast of Australia. Data parameters are listed in Table 14.

TABLE 14. ORBIT 95 SEQUENCE DATA.

IMAGE	GMT	MET	LAT	LONG	ELEV	ORBIT	LENS	FILTER	GSD
11024	104/03:57:38	05/22:28:37	36.9S	098.7E	161nm	95	180mm	H4	25.1m
11025	104/03:58:36	05/22:29:35	39.6S	101.8E	161nm	95	180mm	H4	25.1m
11028	104/04:00:56	05/22:31:55	45.9S	110.6E	160nm	95	180mm	H4	24.9m

Figure 13 depicts the GMS IR satellite view of the region southwest of Australia for 13 April 1993, with orbits 94 and 95 for the following day (14 April) superimposed. This view was used for planning input to a Flight Note for early 14 April. Low stratus development is evident, with a good potential for shiptrack formation, so the crew was notified to take images in this area.

Figure 14 shows the 14 April GMS view of the same region, this time with the upcoming orbits for 15 April. Although the time of the satellite view (1932Z) does not exactly match that of the HERCULES images (roughly 0400Z), it still provides a "big-picture" indication of the actual cloud conditions which were present when the HERCULES images were taken. Figure 15 shows an enlarged view of the area. Figures 16, 17, and 18 show the corresponding HERCULES images listed in Table 14 above. These figures provide an indication of the type of planning required (and degree of difficulty encountered) in determining which regions to image.

Figure 13: 13 1625Z April 93 GMS IR View Overlaid with Next Day's (14 April) STS-56 Orbits.

Figure 14: 14 1932Z April 93 GMS IR View Overlaid with Next Day's (15 April) STS-56 Orbits.

Figure 15: 14 1932Z April 93 GMS IR Enlarged View. Overlaid with 15 April STS-56 Orbits.

Figure 16: ESC 11024 Image.

Figure 17: ESC 11025 Image.

Figure 18: ESC 11028 Image.

b. "Discovery"/"Discoverer" Case

The potential overflight of "Discovery" imaging NOAA ship "Discoverer" mentioned in Chapter IV illustrates two useful points. First, it is critical for the shiptrack investigator to be cognizant of any changes to the Shuttle ephermeris which will affect the orbit ground trace. Second, it emphasizes the requirement that the planned MAST experiment have its own separate access to the satellite cuing imagery. A potential rendezvous time of 14 1537Z April 93 (MET 06/1008) was computed, based on the STS-56 Mission Planning Chart and reported ship's position. This time was submitted in the Execute Package. However, in the interim, an update to the Shuttle ephemeris occurred. This shifted the rendezvous MET by one minute, to 06/1009. Figure 19 depicts the originally plotted intercept, while Figure 20 shows the 1546Z GOES satellite view with the updated orbit trace plotted. Unfortunately, this change was not realized by the author until after the fact. Had it been known beforehand, an updated MET could have been relayed to the crew.

The crew reported that no ship or shipwake was visible at the original time of intercept, and no image was taken at either time. Image ESC 12014 was the closest taken, with an MET of 06/1014, some 1000nmi down track. This case clearly illustrates the rapidity at which ground distance is covered from this orbit; within 30 seconds, the Shuttle is

effectively out of imaging range of a potential target. However, in this case, even if the correct time had been relayed, the meteorological conditions at the point of overflight indicate that the ship was behind a front in an area of broken clouds not conducive to shiptrack formation, i.e., it did not matter, since nothing of interest could be imaged, anyway.

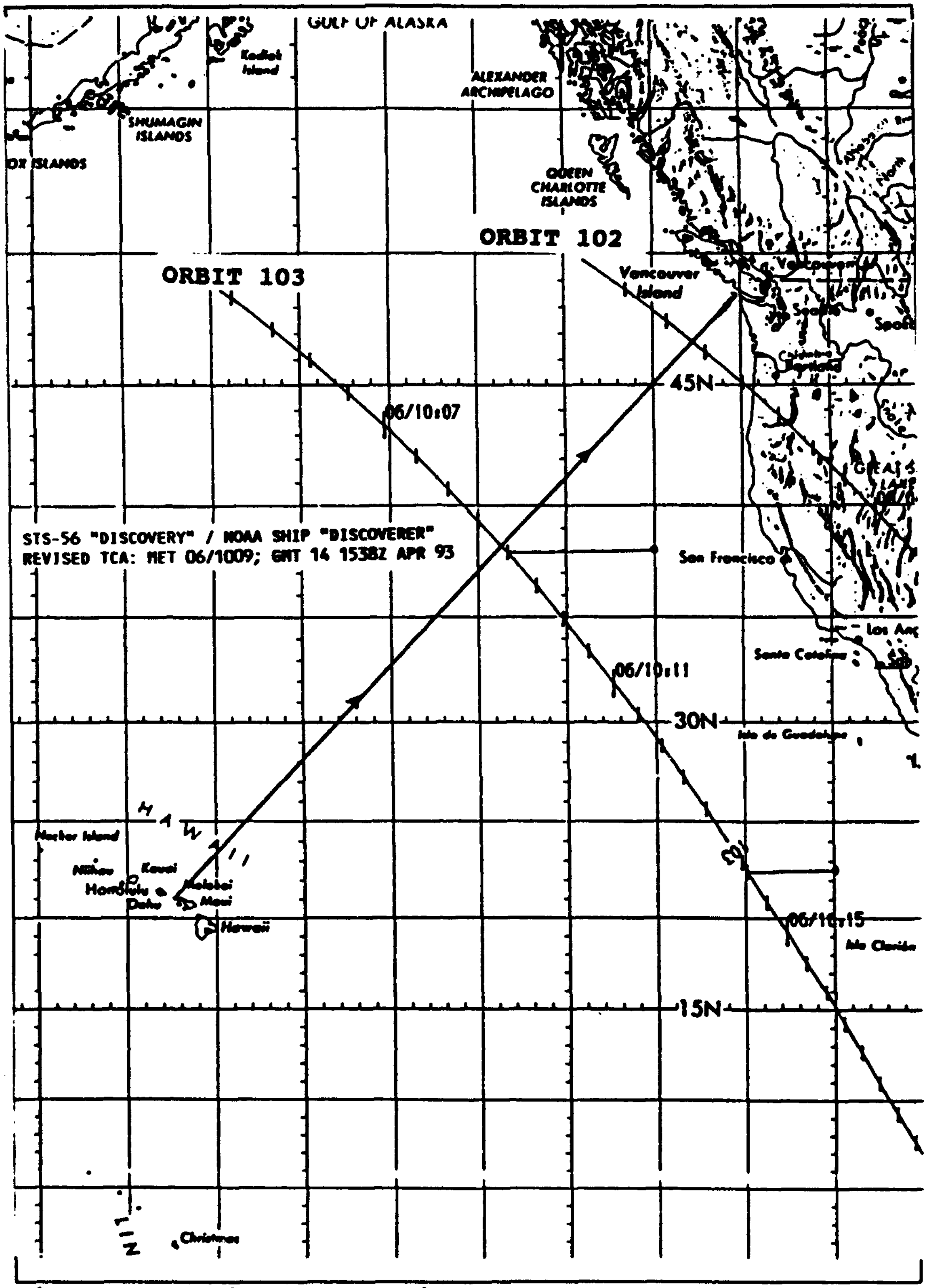


Figure 19: "Discovery"/"Discoverer" Plotted Intercept.

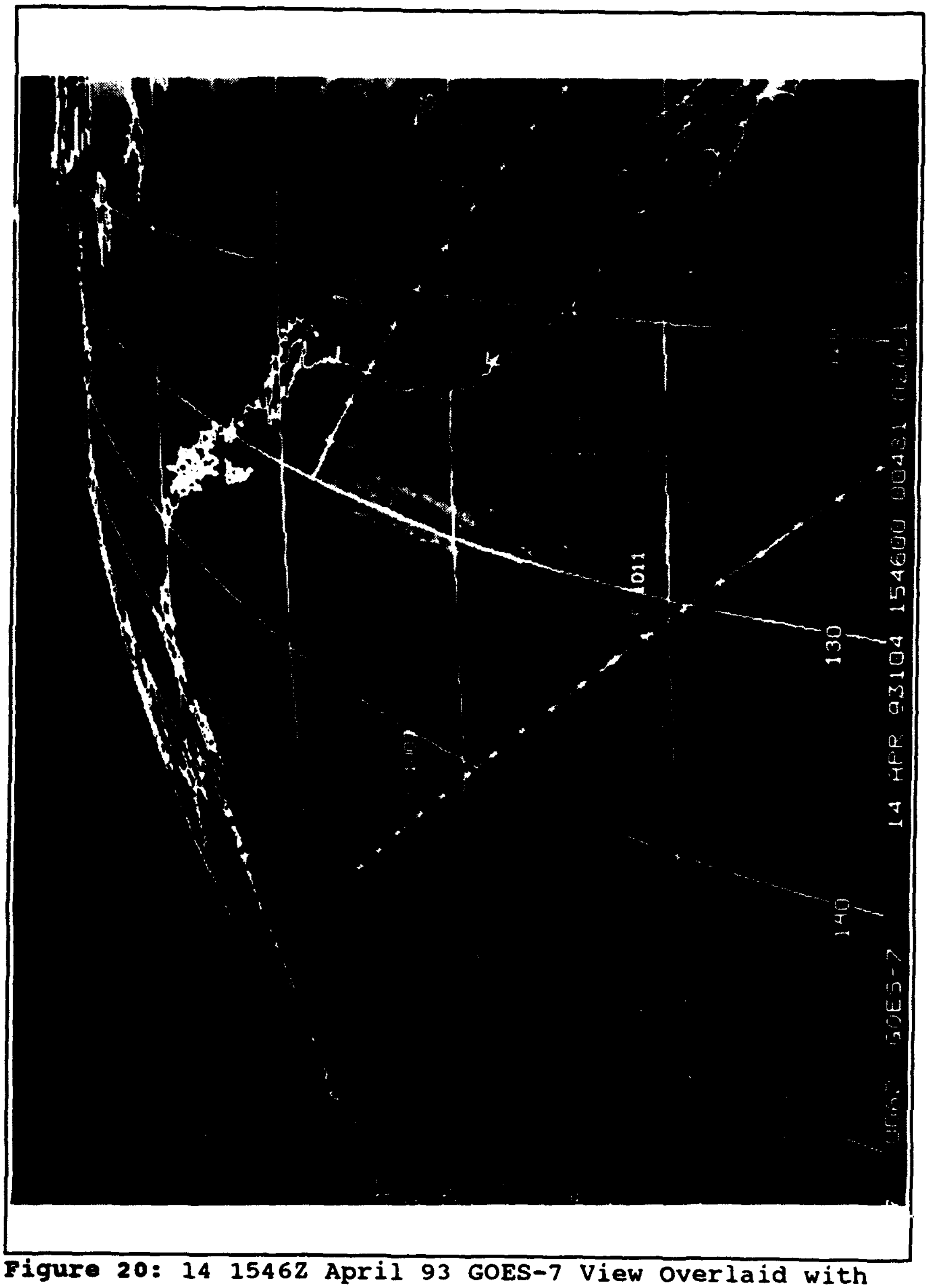


Figure 20: 14 1546Z April 93 GOES-7 View Overlaid with STS-56 Orbits 102 and 103.

c. Orbit-To-Area Match

Figure 21 illustrates one of the difficulties (frustrations) encountered in conducting the shiptrack investigation with the Shuttle. Numerous shiptracks are clearly visible off the California coast in this enlarged GOES image of 14 April 93. Unfortunately, the Shuttle's orbital track is over 600 nmi from the main cluster of shiptracks--too far to allow any images to be taken. This very problem occurred in the case of four U.S. Navy ships in transit under the proper shiptrack formation conditions mentioned in Chapter IV.

At a 57 degree inclination, 160 nmi nominal altitude orbit, the Shuttle's period is 90.4 minutes. The ground trace of each successive orbit is displaced westward by approximately 1200 nmi. This means that a Shuttle with these orbital parameters will "retrace" approximately the same ground track once every 16 orbits (24.1 hours). Therefore, only one opportunity exists to image any shiptrack features detected in a given area per day. For a nominal seven to nine day mission, a corresponding number of traces over the same area would be seen, but crew time would not necessarily be dedicated to shiptrack investigation in each instance, since other on-orbit duties may be scheduled.

Figure 21: 14 1546Z April 93 GOES-7 Enlarged View Overlaid with STS-56 Orbit 103.

VI. MAST PAYLOAD

A. OVERVIEW

As discussed in Chapter I, the actual MAST payload is scheduled for a series of Shuttle flights, with the first commencing in mid-1994. The following information is included to provide a basis for comparing the various hand-held photography systems (including HERCULES) which can be utilized for MAST.

First, an example of imagery taken during a previous Shuttle flight (STS-43), with coincident AVHRR imagery, is presented. Other hand-held cameras which could be utilized for the MAST payload are discussed, and a comparison is made with the HERCULES system. Finally, documentation input which was provided to NASA JSC for the MAST experiment is presented.

B. STS-43 CASE

Shuttle mission STS-43 flew in early August 1991. On 08 August, 35mm hand-held color imagery (using a 250mm lens) of ship cloud tracks along the Monterey, California coast was obtained. AVHRR imagery archives were searched for imagery coincident with this Shuttle observation. Figures 22 and 23 depict the Shuttle and NOAA-11 (channel 3) images, respectively.

Even a simple visual comparison between the two types of imagery shows the additional amount of detail that is discernable with the higher resolution hand-held Shuttle image. Individual track features are evident, and it is also possible to distinguish the track head formation region in one of the tracks turning eastward toward Monterey Bay. Detailed measurements of specific track features in the STS-43 photo can be performed by knowing the orbital altitude, image center point, and image field of view. However, since this image is film-based and not digitized, computerized measurements (e.g., pixel counts) like those performed on the STS-56 HERCULES images, cannot be directly employed. Instead, physical measurements must be taken directly from the photograph itself. Alternatively, the photograph could be "digitized" (i.e., a digital image produced of the photograph), and then pixel measurements made from this image. Either method requires more time, effort, and expense than that experienced when working directly with an "original" digital image. For example, at NASA JSC, the digitization process for one photograph requires approximately 30 minutes to complete [Ref. 25].

Figure 22: STS-43 Image S43-604-046 of 08 August 1991. Cloud Shiptracks Off Monterey, Calif., Coast.

Figure 23: 08 August 91 NOAA-11 Image. Cloud Shiptracks Off Monterey, Calif. Coast.

C. OTHER HAND-HELD CAMERAS

In assessing the utility of the HERCULES system, it is useful to discuss the capabilities of other hand-held cameras which NASA astronauts use for Earth-imaging. These are also the cameras which can be used for the MAST payload. While small-format cameras (35mm Nikon, 16mm Arriflex motion-picture) can also be utilized, their images are not as useful. Instead, the Hasselblad and Linhof camera systems are the two most commonly used for Earth-imaging. Their film is catalogued and archived by the NASA JSC Earth Observation Laboratory.[Ref. 26:p. 59]. Data parameters for each of these cameras is listed in Table 15.

TABLE 15. HASSELBLAD AND LINHOF CAMERA SYSTEMS DATA.

		FOV AT NADIR for 160nmi ORBIT	
CAMERA	**LENS**	**km**	**nmi**
HASSELBLAD	50mm	325	175
	100mm	165	90
	250mm	65	35
Film size: 70mm. Exposures per magazine: 100-130. Other lenses available (but not commonly used): 40mm, 500mm			
LINHOF	90mm	310 x 395	170 x 215
	250mm	110 x 145	60 x 75
Film size: 5 inch,producing a 4 x 5 in. photo. Exposures per magazine: 200.			
Note: For both cameras, the 100mm lens offers spatial resolution of approximately 80m; for the 250mm lens it is approximately 30m.			

Source: [Ref. 26:pp.60-61] and NASA JSC Flight Science Branch pamphlet "Space Shuttle Earth Observations Photography", January 1993.

1. Hasselblad (NASA-modified 500 EL/M 70mm)

This is the camera most often used for Earth observation photographs. Since the camera does not have automatic exposure control, manual settings are required. Typically, a 1/250 second shutter speed is used with standard ASA 64 film. Lenses larger than 250m are not used due to Shuttle window imperfections and contamination.[Ref. 26:p. 59].

2. Linhof (AeroTechnika 45)

This camera is actually classified as large-format. Although it takes up more space, crewmembers consider it relatively easy to use. The Linhof camera system can provide excellent quality photographs, and its larger film size permits larger area coverage of a given scene with a corresponding spatial resolution equivalent to that of the 70mm Hasselblad.[Ref. 26:p. 60].

3. Associated Equipment

a. Data Recording Modules (DRMs)

DRMs can be attached to the film magazines of both the Hasselblad and Linhof cameras. The DRM imprints the date, GMT, mission number, film type, magazine number, and frame number along the edge of each frame of the film when an image is taken. The DRM data is combined with Shuttle ephemeris data to determine the latitude/longitude, altitude, sun azimuth and elevation, and orbit number for the nadir point at

which the image was taken. Using this information, photo interpreters then calculate image center point position, orientation, per cent cloud cover, and site description for the scene.[Ref. 26:p. 61-62]. For shots of open ocean, barren land, or extensive cloud cover, where no recognizable landmarks are evident, only the Shuttle position is known (but not the scene location).

b. Dual Mount

Two Hasselblad cameras can be fastened to a dual mount designed and built by NASA JSC. This device facilitates simultaneous photography of the same site, which is useful in polarization, film-speed, and film type comparisons.[Ref. 26:p. 62]

4. Kodak Hawkeye M1 CCD Camera (KAF-1400V)

This camera was field tested by Kodak in July 1990, and has flown on two shuttle mission, most recently on STS-54 in January 1993. The system has a hard disk storage unit for electronically recording the images taken. Various lenses can be interchanged for use with the camera. The field test utilized a 50-300mm zoom lens (tested at 50, 200, and 300mm focal lengths), as well as 1.4x and 2x teleconverters to increase the focal length variations [Ref.27:p. 5]. CCD size is approximately 8mm by 7mm [Ref. 27:p. 14]. Whereas the theoretical Ground Resolved Distance and Field of View values were computed for an orbital altitude of 190 nmi in the study

[Ref 27, p. 21], they are recomputed for a 160nmi orbit in Table 16 for comparison with the HERCULES ESC. Essentially, the Kodak M1 is capable of a higher resolution, but has a correspondingly lower ground field of view than the HERCULES ESC.

TABLE 16. KODAK M1 CAMERA CALCULATIONS FOR 160 nmi ORBIT.

LENS (mm)	GROUND RESOLUTION (m)	APPROX. FOV (nmi)
50	39.2	28 x 22
180	10.9	7.1 x 6.2
300	6.5	4.2 x 3.7
420	4.6	3.0 x 2.7
600	3.2	2.1 x 1.9
1000	2.0	1.3 x 1.1
Note: Based on CCD chip size 1325 x 1035 pixels, and pixel size of 6.7 microns.		

The field test concluded that the Kodak M1 performed well, with the Nikon zoom lens (50-300mm) given the best overall rating.[Ref. 27:p. 25]. The author viewed imagery from the STS-54 mission taken with this camera, and discussed its use with the primary astronaut operator (LCDR Mario Runco, USN). The imagery viewed was of comparable quality to that of the HERCULES ESC, and the camera was considered easy to operate.

No downlink or geolocation capability is presently available with this camera. In theory, with some modifications, the HERCULES system could be connected to this camera to provide geolocation information; however, such a

modification would require field testing and space flight qualification (as well as funding for the modifications). No such plan is presently under consideration.

As with the HERCULES ESC, only panchromatic imagery is possible with the Kodak M1. This camera allows "rapid-fire" sequences of images to be taken, contrasted with the 20-30 second processing delay experienced between image takes with the HERCULES ESC. Contractor support for the Kodak M1 is currently not available, although the camera and equipment are on inventory with the U.S. Air Force SMC/CULH office at NASA JSC. In order to take full advantage of the digital imagery taken with the Kodak system, the imagery requires conversion into a format that is widely used by image processing systems (e.g., TARGA, GIF, TIF, etc.).

5. HERCULES ESC Versus 70mm Hasselblad Comparison

a. Description

A comparative evaluation of space-based imagery obtained from these two cameras was conducted in 1992 as a planning measure for the proposed Space Station Freedom [Ref. 28:p. 1]. An updated analysis, focused specifically on the Space Shuttle applications, was performed in 1993 [Ref. 29:p. 1]. These studies analyzed two sets of simultaneous image pairs taken from the two cameras in quantitative and qualitative terms [Ref. 28:p. 7]. The Hasselblad photographs were digitized and size-matched, then compared to the ESC

images in terms of the relative spatial and spectral resolution. Platform blur due to Shuttle motion, resolving power, and quantum efficiency were addressed. A graphical comparison of the limits of resolution of the two camera systems was displayed, and reproduced here as Figure 24. [Ref. 29:p. 5].

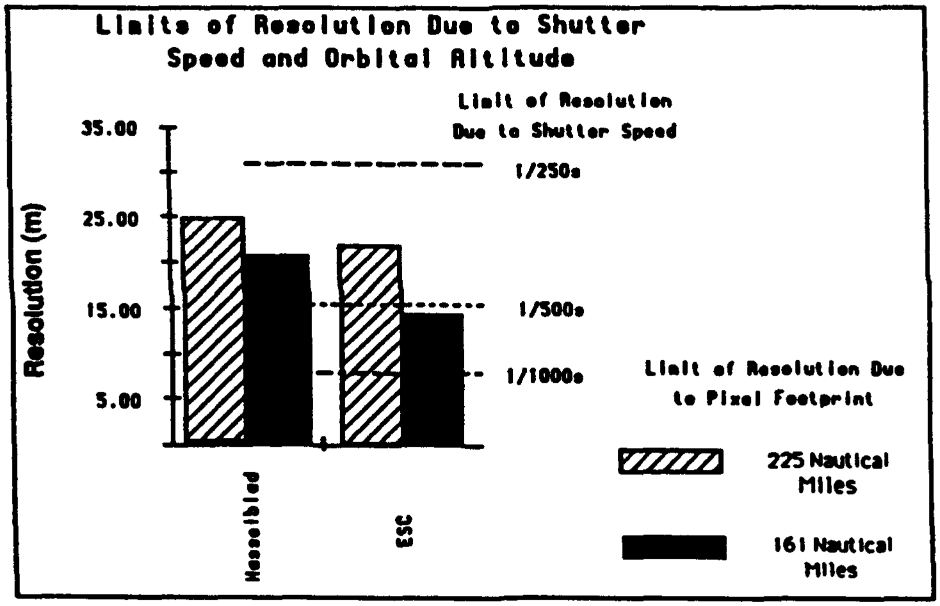


Figure 24: Comparison of HERCULES ESC and Hasselblad Camera Limits of Resolution. **Source:** [Ref. 29:p. 5].

The resolution/shutter speed (exposure time) relationship is calculated from the following expressions:

$$v = ((G*M)/r)^{.5} ,$$

where v = Shuttle tangential velocity (circular orbit)

$$G*M = u = 3.986 \times 10^5 \ km^3/s^2$$

r = (radius of Earth = 6371.2 km)+(Shuttle altitude = 296.3km)
= 6667.5 km

Solving for the above gives v = 7.73 km/s

The ground blur (limit to resolution) at various shutter speeds can be calculated as:

ground blur = v * (exposure time)
= 7730 m/s * (e.g., 1/500 s)
= 15.45 m

b. Results/Conclusions

The following are extracted from [Ref. 28:p. 20] and [Ref. 29:p. 8]:

- A Fourier spatial frequency analysis was conducted to define each camera's ability to recognize edges within an image. With this technique, sharp edges within an image originate from high frequency components, while general scene quality results from lower frequency components. The analysis showed that in predominantly low-frequency images, the two systems were comparable. With predominantly high-frequency images, the ESC contained more detail and had better edge discrimination (e.g., roadways, buildings, etc.).

- At a Shuttle altitude of 160 nmi, the ESC and Hasselblad have comparable spatial resolution. A difference in resolution is seen at higher altitudes. For example, at a 225 nmi altitude, the ESC resolution is 20m, while the Hasselblad resolution is 25m.

- Qualitatively, the ESC images appear sharper; the digitized Hasselblad scenes have poorer resolution.

- The current ESC field of view often does not facilitate some Earth-observation applications. By utilizing a larger CCD chip, and increasing chip density, improvements can be realized.

- ESC scene element contrast can facilitate feature detection and identification.

- Since Hasselblad photographs are usually in color, they often can offer the human investigator important image interpretation cues not available with the present ESC panchromatic imagery.

- Since ESC imagery is panchromatic, it has limited applications in Earth mapping and Earth-resource monitoring. Often, the larger field of view offered by medium and larger format film cameras is needed. Therefore, at present, the HERCULES ESC and film cameras are complementary in nature.

6. Input To MAST Payload Integration Plan (PIP)

A MAST PIP and Interface Control Document (ICD) Review meeting was conducted at NASA JSC on 15 July 1993, to facilitate planning and documentation requirements for the payload. The author and his advisor were in attendance; subsequently, planning input for two PIP documents (Annex 2 and Annex 3) were provided to the Air Force STP SMC/CULH office at JSC. Copies of these inputs are found in Appendix E. The Annex 2 input specifies (in priority order) coordinates for world-wide MAST imagery coverage. Flight planners will schedule MAST observation "data take" times to coincide with the daylight orbital tracks which traverse these areas. The Annex 3 input essentially identifies the type of

image scenes desired, and the camera/lens combinations to be used for the experiment's initial flight.

For the initial flight, the intent is to maintain operational simplicity in order to establish a firm knowledge base (e.g., procedures, capabilities, etc.) for follow-on MAST missions. Therefore, it is specified that the Hasselblad and Linhof cameras be utilized without any special filters, film, or mounts. These items can be tried on subsequent flights, pending the results produced on the initial flight.

VII. CONCLUSIONS AND RECOMMENDATIONS

The purpose of this thesis is to assess the utility of the Project HERCULES system in the investigation of ship cloud tracks, in particular the MAST study, as well as other Naval-related applications. Specifically, the utilization of the HERCULES system in these applications during the STS-56 Space Shuttle mission was studied. The integration of operational, procedural, and support requirements (similar to those expected for the MAST payload) before and during the mission were described, and a representative analysis of five cases was presented, along with descriptions of alternative camera systems.

The HERCULES system, as demonstrated on the STS-56 mission, does have utility as an investigative tool in the study of ship cloud tracks and in the MAST experiment. The system's capability of providing usable geolocation information on open-ocean features was shown, and is its primary advantage. HERCULES resolution performance and real-time image downlink capability were successfully demonstrated on the mission. These features, along with the versatile digital format of the imagery, make the HERCULES system an attractive combination.

However, while a sufficient quantity of images of interest were taken, it is evident that timely and accurate cuing is

needed to ensure success of the MAST experiment. Whereas the exact geolocation of a shiptrack feature is highly desirable, it is not a limiting factor in camera selection. More important are the resolution and field of view considerations, since positional information can be either estimated using existing procedures, or effected through ground truth mechanisms (especially in a dedicated field experiment such as that planned for MAST in the summer of 1994). From the present scientific standpoint, resolution of features (e.g. track head distance and dimensions) and scene coverage are more critical than precise geolocation.

Downlink capability does offer some potential utility in the shiptrack investigation, in that a "real-time" review of image type and quality is possible, with any needed adjustments relayed to the operator. In a field study, it could potentially assist in directing any participating ships in some track-forming maneuver which would provide a desired data point. However, such an application is highly time-dependent; beyond a time delay of three hours, the usefulness of this capability in such a study is greatly diminished.

The requirement for state-vector updates and star alignments makes the HERCULES system labor-intensive in comparison to other hand-held cameras. This burden can be eliminated if/when a Global Positioning System (GPS) receiver is outfitted in the Space Shuttle, and an interface made

between the GPS receiver and the HERCULES system. NRL is investigating this possibility. [Ref. 30].

The most critical limitation of the HERCULES system is the 20 to 30 second processing time-delay required between image takes. This means that only one image is possible per orbital pass over a given area or potential shiptrack feature. From a practical standpoint, this temporarily eliminates the HERCULES system from routine use in the MAST experiment. Work is currently underway to reduce this delay to one second [Ref. 31].

Although numerous ship positions were monitored during the mission, none were correlated to any shiptrack formations, nor were any images obtained of these vessels. In part, this illustrates the difficulty of attempting an experimental study by utilizing non-dedicated operational assets. Portions of the MAST experiment will have dedicated assets with which to work, thereby alleviating some of this difficulty.

With regard to computer resources and satellite data collection for the MAST experiment, several recommendations are offered:

- A computer capability to plot ship locations through continuous tracking with course/speed inputs is needed. This, combined with the capability to overlay the Shuttle orbital track, can better determine intercept times and positions.

- A system which can overlay satellite orbits (NOAA, DMSP) as well as the Shuttle orbit is needed in order to provide view times, swath coverage, and real-time planning.

- A JOTS system or separate classified computer that can maintain track and position information on U.S. Navy ships worldwide is recommended.

- Continuous access to all NOAA AVHRR imagery at a separate MAST workstation is required.

- Arrangements for collecting and archiving satellite data (including high-resolution DMSP), particularly over areas of anticipated ship cloud track formation, should be made in advance of the MAST mission. This will greatly facilitate post-mission analysis.

- The Shuttle crew should be cued to potential areas and/or present locations of ship cloud tracks with uplinked hard-copy satellite imagery, via the TIPS or TAGS systems, on a regular basis.

- A means of automatically receiving periodic reports of course, speed, and position information for any NOAA or merchant ships in the vicinity of areas conducive to ship cloud track formation should be implemented.

- At least two persons should be employed to conduct the experiment operations at JSC during the mission--one to handle ship position information, and one to handle the satellite data information systems and interpret the weather imagery.

Shuttle flights offer the MAST experiment the opportunity to study and obtain imagery of ship cloud track formation over a specified time period on a worldwide scale. This opportunity can be optimized through careful selection of camera systems, proper implementation of computer support, and full exploitation of available satellite imagery.

APPENDIX A

EXAMPLE OF STS-56 HERCULES STATION CONTACT SUMMARY LIST

11/16/92 3:43 PM

HERCULES STATION CONTACT SUMMARY

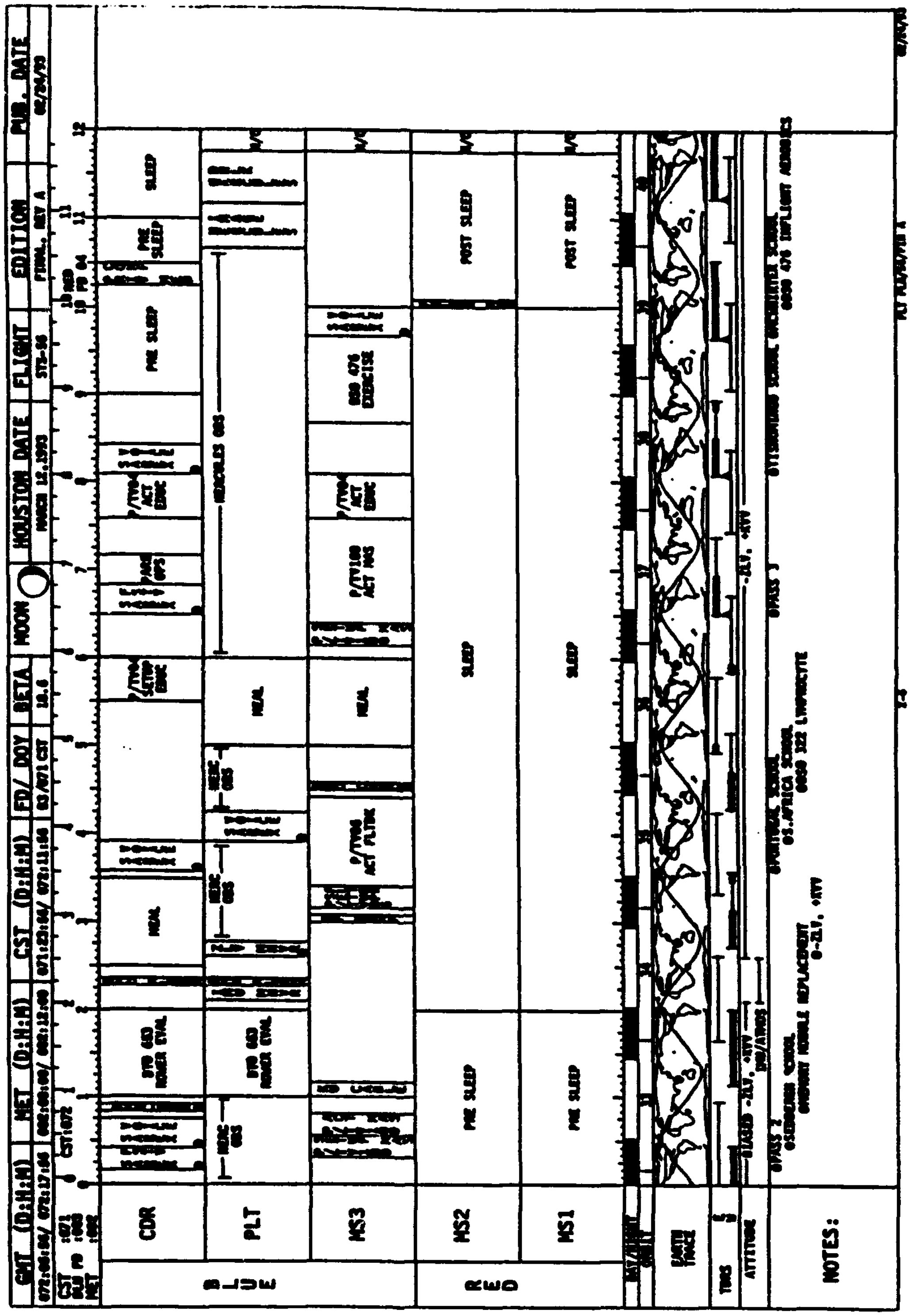
STS: 56 LAUNCH DATE/TIME (GMT): 23 MARCH 1993 / 0:05:59:00:00 FAO Special

FILTERS: Max El >= 60°

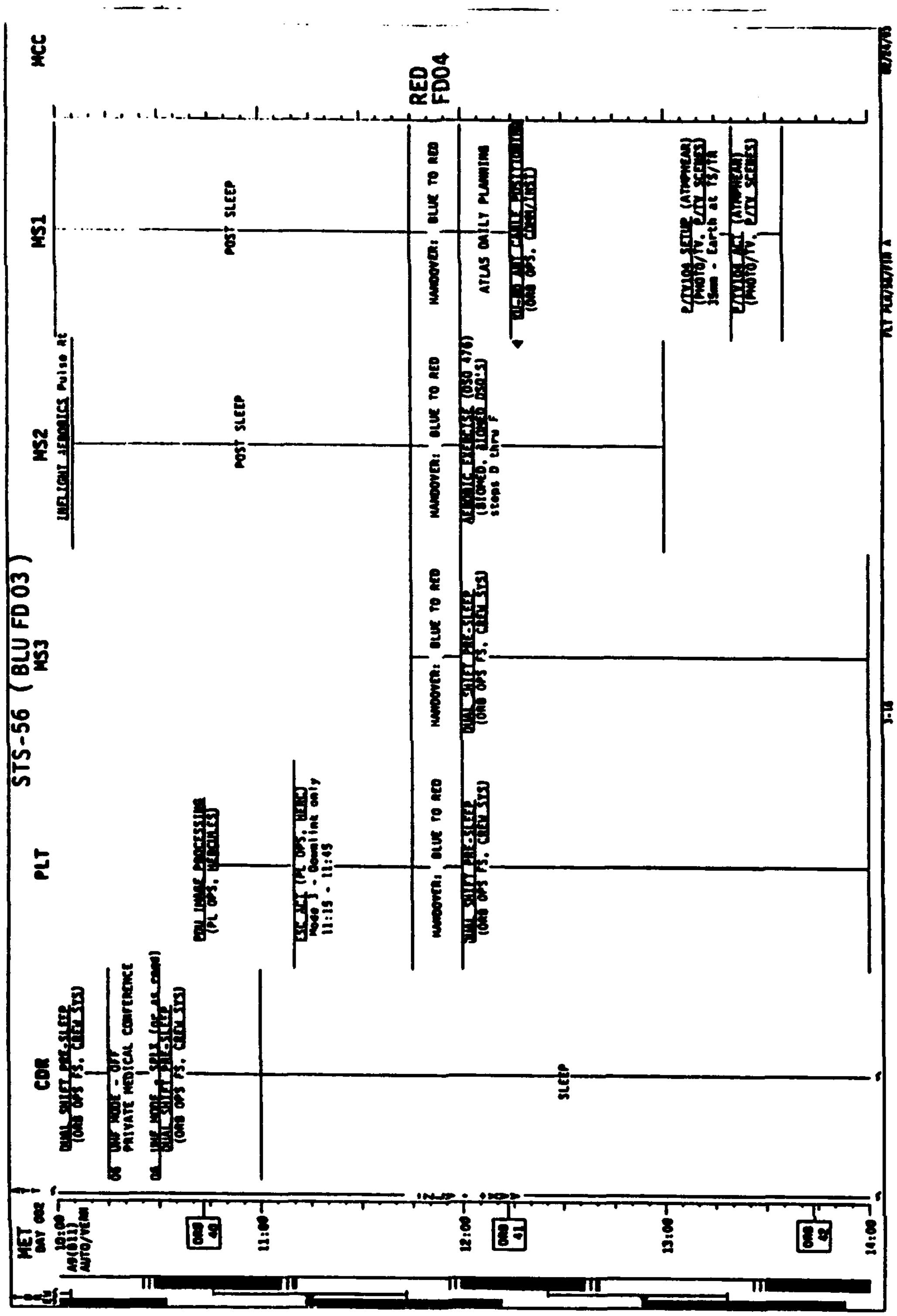
SITE NAME (ID) #	CFB #	GMT (AOS-DHMS)	AOS (MET-DHMS)	TCA (MET-DHMS)	LOS (MET-DHMS)	SUN EL (DEG)	XTRACK (DEG)	LAT (DEG)	LONG (DEG)	FILTER	LENS TYPE	EXPERIMENT
Golden Gate Brigde	66	86:08:04:20	4:02:05:20	4:02:05:35	4:02:05:51	-50	22.2	37.727	-122.223	N/A	300	GROUND RES.
Raindeer Is.	66	86:08:10:01	4:02:11:01	4:02:11:25	4:02:11:49	-32	6.4	52.290	-97.950	0	0	GEOLOCATION
Mistastin Lake	66	86:08:15:30	4:02:16:30	4:02:16:46	4:02:17:01	-14	22.9	55.910	-63.300	0	0	GEOLOCATION
Rota NAS	66	86:08:26:35	4:02:27:35	4:02:27:49	4:02:28:02	25	-24	36.625	-6.342	H4	300	GROUND RES.
Straight of Gibralter	66	86:08:26:53	4:02:27:53	4:02:28:04	4:02:28:15	26	-25.5	35.920	-5.500	N/A	180	GEOLOCATION
Mohammedia	66	86:08:27:02	4:02:28:02	4:02:28:15	4:02:28:29	25	24.1	33.720	-7.400	0	0	GEOLOCATION
Maputo	66	86:08:45:17	4:02:46:17	4:02:46:36	4:02:46:55	57	17.2	-25.980	32.600	0	0	GEOLOCATION
Nihan Is.	67	86:09:29:20	4:03:30:20	4:03:30:42	4:03:31:04	-59	9.1	21.900	-160.150	N/A	180	GEOLOCATION
Nelson House	67	86:09:44:03	4:03:45:03	4:03:45:23	4:03:45:42	-20	18.3	55.900	-98.460	ANY	ANY	Ecology
Goose AOT	67	86:09:49:43	4:03:50:43	4:03:51:07	4:03:51:31	0	-2.8	53.320	-60.380	0	0	GEOLOCATION
Kangaroo	67	86:10:42:02	4:04:43:02	4:04:43:25	4:04:43:48	-24	1.7	-35.850	138.140	0	0	GEOLOCATION
Midway Is.	68	86:11:01:59	4:05:02:59	4:05:03:13	4:05:03:28	-57	22.8	28.200	-177.350	N/A	180	GEOLOCATION
Nelson House	68	86:11:17:45	4:05:18:45	4:05:19:09	4:05:19:33	-9	7.8	55.900	-98.460	ANY	ANY	Ecology
Charlton Is.	68	86:11:20:49	4:05:21:49	4:05:22:14	4:05:22:38	2	1.4	51.890	-79.820	0	0	GEOLOCATION
Perth	68	86:12:13:39	4:06:14:39	4:06:14:49	4:06:15:00	-26	-25.8	-32.000	116.830	H2	180	GEOLOCATION
Darwin Intn'l Airport	68	86:12:19:43	4:06:20:43	4:06:21:02	4:06:21:21	-45	-16.6	-12.417	131.871	N/A	180	GEOLOCATION
Darwin International	68	86:12:19:43	4:06:20:43	4:06:21:02	4:06:21:20	-45	-16.6	-12.416	131.867	N/A	'80	GEOLOCATION
Prince Albert	69	86:12:50:32	4:06:51:32	4:06:51:54	4:06:52:16	-1	-12.9	53.860	-106.160	ANY	ANY	Ecology
Winnipeg Intl	69	86:12:52:15	4:06:53:15	4:06:53:39	4:06:54:04	5	-0.4	49.910	-97.240	0	0	GEOLOCATION
Duluth Intl	69	86:12:53:27	4:06:54:27	4:06:54:50	4:06:55:13	8	9.5	46.840	-92.190	0	0	GEOLOCATION
Norfolk Naval Base	69	86:12:57:27	4:06:58:27	4:06:58:48	4:06:59:09	23	-13.8	37.000	-76.500	N/A	300	GROUND RES.
Norfolk NAS	69	86:12:57:30	4:06:58:30	4:06:58:50	4:06:59:11	23	-15.5	36.937	-76.290	N/A	300	GROUND RES.
Norfork NAS	69	86:12:57:30	4:06:58:30	4:06:58:50	4:06:59:11	23	-15.5	36.934	-76.284	N/A	180	GEOLOCATION
Duke Forrest	69	86:12:57:34	4:06:58:34	4:06:58:39	4:06:58:44	21	27.9	36.000	-79.000	ANY	ANY	Ecology
Chickasha	70	86:14:28:28	4:08:29:28	4:08:29:49	4:08:30:12	24	-5.5	34.920	-98.020	ANY	ANY	Hydrology
Dallas/Ft.Worth Airport	70	86:14:28:58	4:08:29:58	4:08:30:22	4:08:30:45	26	7.2	32.897	-97.042	N/A	180	GEOLOCATION
Yucatan Channel	70	86:14:33:02	4:08:34:02	4:08:34:08	4:08:34:14	39	-27.4	22.000	-86.000	H4	180	GEOLOCATION
Sherman AAF	70	86:14:36:22	4:08:37:22	4:08:37:45	4:08:38:08	48	4.7	9.183	-79.967	H4	300	GROUND RES.
Panama Canal	70	86:14:36:28	4:08:37:28	4:08:37:49	4:08:38:12	48	-0.4	9.080	-79.620	H3	180	GEOLOCATION
Omar-Torrcos Herrera Intl.	70	86:14:36:30	4:08:37:30	4:08:37:52	4:08:38:15	48	-6.7	9.067	-79.263	H4	300	GROUND RES.
Utapah Airfield	71	86:15:28:02	4:09:29:02	4:09:29:24	4:09:29:45	-58	-9	12.683	101.000	N/A	180	GEOLOCATION
San Francisco Bay	71	86:15:58:14	4:09:59:14	4:09:59:30	4:09:59:46	22	-21.5	37.610	-122.360	0	0	GEOLOCATION
Golden Gate Brigde	71	86:15:58:17	4:09:59:17	4:09:59:30	4:09:59:43	22	-24.2	37.727	-122.223	N/A	300	GROUND RES.
San Diego Harbor	71	86:16:00:04	4:10:01:04	4:10:01:11	4:10:01:18	28	-27.1	32.700	-117.150	N/A	300	GROUND RES.
Cedros Is.	71	86:16:01:02	4:10:02:02	4:10:02:26	4:10:02:49	31	-1.7	28.030	-115.180	0	0	GEOLOCATION

APPENDIX B

EXAMPLE OF STS-56 SUMMARY TIMELINE



APPENDIX B - CONTINUED
EXAMPLE OF STS-56 DETAILED TIMELINE



APPENDIX C

EXAMPLE: STS-56 EXECUTE PACKAGE-- HERCULES TARGET UPDATE LIST

```
MSG 093 - BLUE FDS HERCULES TARGET UPDATE                        3/22:40
PAGE 1 OF 2. 51 LINES THIS PAGE


                                                                          PHYS
ORB NAME              ID        TCA       XT     LAT    LON   FIL  LEN    EXPER   ATL

65  Mt. Etna          93 4:00:55:36 -15.50 37.75  15.00  NONE 180    Geoloc    5
    Site book #56

66  San Fran Bay     131 4:02:04:13  18.80 37.61 -122.36NONE  INT    Geoloc    2
    Night pass to image light patterns of the bay area, including the
    Golden Gate Bridge on the west side of the bay.

66  Mohammedia        89 4:02:26:54  27.80 33.72  -7.40  NONE 50     Geoloc    14
    Site book #54

66  Maputo            82 4:02:45:08  16.40 -25.44 32.58  Pol  50     Geoloc    38
    Site book #51.

67  Cape Town         24 4:04:18:32  -9.80 -33.97 18.60  H10  300    Gnd Res   37
    Site book #15.

67  Adelaide             4:04:42:23 -16.80 -34.55 138.55 NONE INT    Gnd T     28
    Image light pattern. Center image on the city.

67  Between MET 4/04:10:00 and 4/14:18:00 observe ship cloud tracks and
    oceanographic tragets of opportunity off coast of W. Africa.  Use
    50mm lens and H4 filter.

69  Norfork NAS      102 4:06:57:33 -11.90 36.93 -76.28  NONE 1000   Geoloc    2
    Naval station on south side of Chesapeake Bay.  Center image on
    runway of naval air station.

69  Between MET 4/06:58 and 4/07:03 observe sunglint, shipwake, and
    oceanographic targets of opportunity exist in the Atlantic Ocean.
    Use 300mm lens and H4 filter.

70  Denver, Co           4:08:26:38  26.30 39.45 -105.50 NONE 300X2 Resolut    2
    Center image on city.

70  DFW Airport       34 4:08:29:05  11.40 32.90 -97.04  NONE 300X2 Geoloc    2
    Center on the airport.  Airport located between Dallas and Fort
    Worth toward the north side of the cities.

END OF PAGE 1 OF 2.  MSG 093
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MSG 093 - BLUE FDS HERCULES TARGET UPDATE
PAGE 2 OF 2, 43 LINES THIS PAGE

70 Between MET 4/08:30 and 4/08:35 sunglint, shipwake, and oceanographic targets of oportunities exist in the Gulf of Mexico.

70 Panama Canal 109 4:08:36:33 5.10 9.08 -79.62 H3 300 Geoloc 12
Center image on canal. Objective is to image traffic in canal.

71 Utopah Airfield 153 4:09:28:09 -14.10 12.68 101.00 NONE 180 Geoloc 20
Site book #91.

71 Golden Gate Brdg 49 4:09:58:15 -21.20 37.73 -122.22 NONE 1000 Gnd Obs 2
Center image on bridge. Bridge located on the west side of San Francisco Bay.

71 Between MET 4/09:54 and 4/10:02 good conditions for ship cloud tracks. Look for anomalous linear cloud lines in low stratus off north California coast near San Francisco and Monterey. Use 180mm lens and H4 filter. If downlinking, use alternate camera (250mm, CVIS or CIR).

71 Camp Pendelton 4:09:59:48 -27.10 33.25 -117.34 NONE 1000 Resolut 2
Located along the coast, north of San Diego. Identifiable by break in urban area along the coast. Center image on runways adjacent to coast line.

71 S. Georgia Is. 4:10:28:46 -9.90 -54.15 -36.45 NONE 300 Erth Obs 42
Eastern and Southern most island of the Falkland Islands. Center image on mountain peaks on the center of the island.

72 Between MET 4/11:25 and 4/11:35 conditions good for detecting ship cloud tracks. Look for anomalous linear cloud lines in low stratus on either side of track. Use 180mm lens and H4 filter.

END OF PAGE 2 OF 2, MSG 093

APPENDIX D

HERCULES PROJECT MANAGER STS-56 POSTFLIGHT STATUS REPORT SELECTED EXCERPTS

Hercules Geolocation Accuracy and Resolution Analysis.
A preliminary report

Total number of images obtained = 507 (13 disks with 39 images per disk)

Images with stars - used for Hercules geolocation	= 176
Images with in-cabin shots	= 15
Images that were geolocated by BOL and have Hercules information	= 86
Images that were geolocated by BOL but have no Hercules information	= 20
Images that were qualitatively located by BOL i.e general area description	= 23
Images that were not geolocatable by BOL	= 187

(These could be unidentifiable land shots, ship wakes, clouds, moon shots, earth's limb and unidentifiable image intensifier images)

The following notation is used to derive the expressions of the various parameters.

r = Radius of earth. The earth is modeled as a sphere of radius = 40000 km.
a = Angle subtended by the arc joining the Verified & Hercules coordinates.

$Cos(a) = Cos(Latitude_{Ver.} - Latitude_{Herc.}) \times Cos(Longitude_{Ver.} - Longitude_{Herc.})$

h = elevation of the orbiter.
b = Angle subtended by the arc joining the Verified & Orbiter coordinates.

$Cos(b) = Cos(Latitude_{Ver.} - Latitude_{Orb.}) \times Cos(Longitude_{Ver.} - Longitude_{Orb.})$

h = elevation of the orbiter.
w = CCD size = 15.36 mm.
f = focal length of the lens.
c = half of the Field of View of the ESC

2*tan(c)= CCD size/focal length = pixel size at nadir/h

d = slant angle between the orbiter altitude and the Verified coordinates.

Sin(d) = r*Sin(b)/range.

The error in geolocation was determined by computing the curvilinear distance between the verified coordinates of the geolocated image and its Hercules coordinates.

Error = r * a

The range was calculated by the following expression

Range = r*r + (r+h)*r+h) - 2*r*(r+h)Cos(b)

The Ground Spatial Distance (GSD) is the pixel size at nadir.

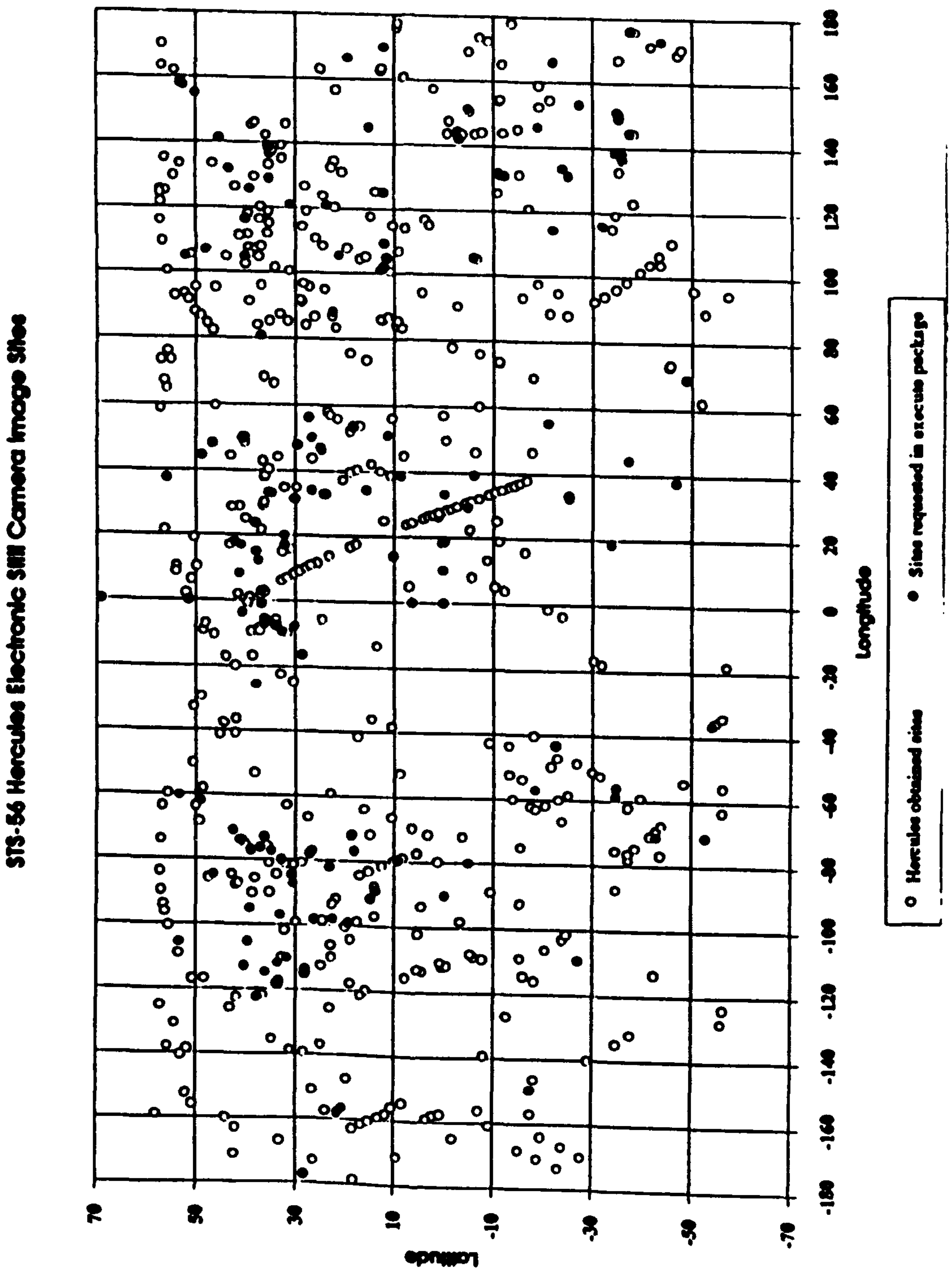
GSD = h * w /f

The Y resolution is the vertical size of the pixels in the image.

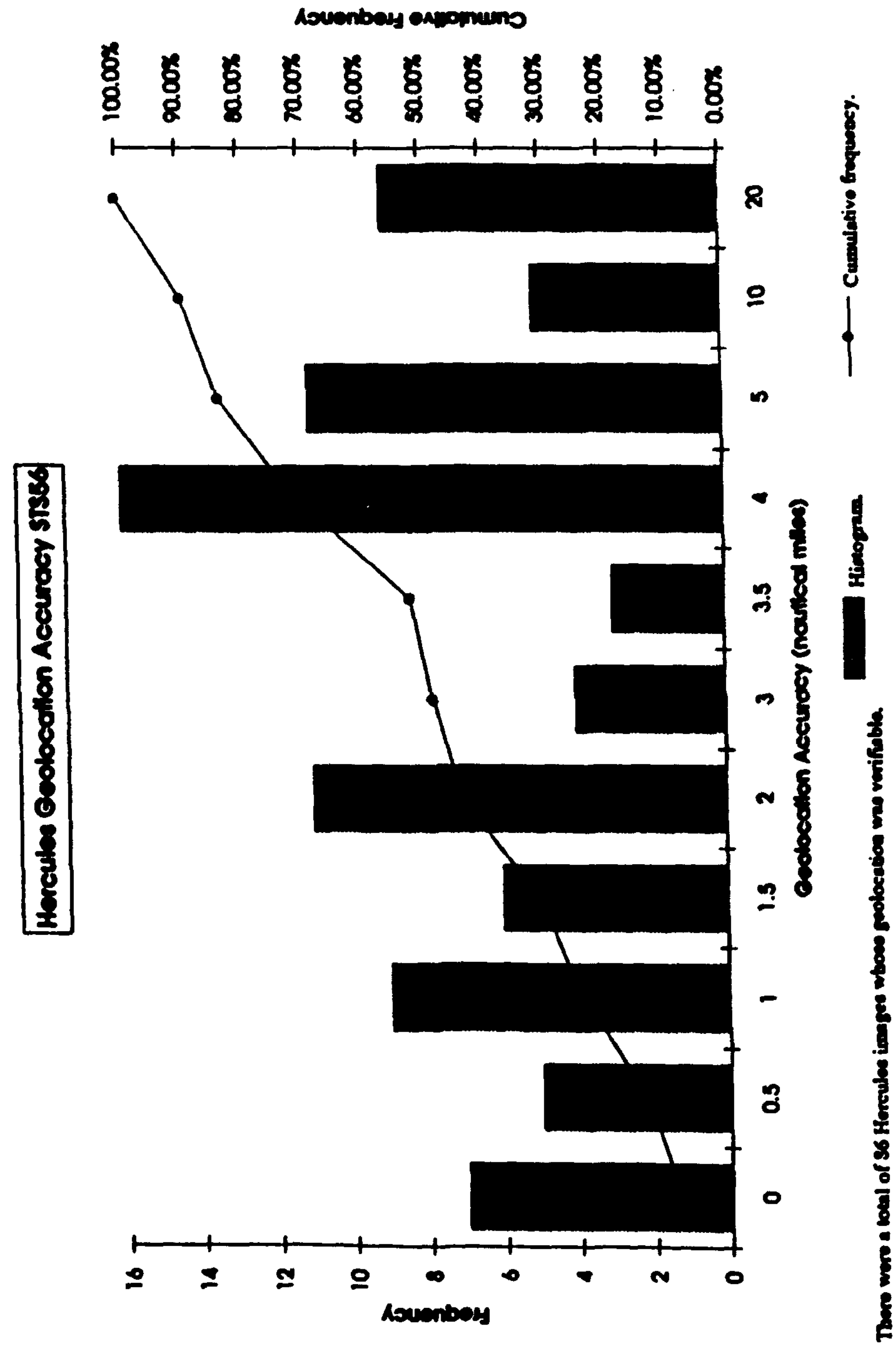
$$\text{Y resolution} = \frac{2 * h * \tan(c)}{[\mathrm{Cos}(d)^2\{1 - \tan^2(c)\tan^2(d)\}]}$$

The X resolution is the horizontal size of the pixels in the center row in the image

$$\text{X resolution} = \frac{2 * h * \tan(c)}{\mathrm{Cos}(d)}$$


STS-56 Hercules Electronic Still Camera Image Sites
Longitude
Latitude
180 160 140 120 100 80 60 40 20 0 -20 -40 -60 -80 -100 -120 -140 -160 -180
70 50 30 10 -10 -30 -50 -70
Hercules obtained sites
Sites requested in execute package

APPENDIX D - CONTINUED



STS-56 HERCULES ESC DISK 6 IMAGERY DATA LISTING

S.No.	Dsk	Img	Date	GMT	MET	Here Lat	Here Lon	orbLat	orbLon	EOL Lat	EOL Lon	Elev	Orbit	Lens	Filt.	GSD	Exp.M	##	Sh.Sp	Exp.C
157	6	1	4/10/93	100/15:29:54.34	02/10:00:54	-15.59	-74.851	-15.7	-73.1	-15.58	-74.85	160	39	300	999	15	S	f/999.0	500	-0.667
158	6	2	4/10/93	100/19:50:50.59	02/14:21:50	18.371	-162.65	18.5	-162.3	0	0	159	42	180	4	24.8	S	f/999.0	125	-2
159	6	3	4/10/93	100/19:51:23.79	02/14:22:23	16.566	-161.21	16.7	-161.2	0	0	159	42	180	4	24.8	S	f/999.0	125	-2
160	6	4	4/10/93	100/19:51:52.17	02/14:22:52	15.087	-160.26	15.2	-160.2	0	0	159	42	180	4	24.8	S	f/999.0	125	-2
161	6	5	4/10/93	100/19:52:28.62	02/14:23:28	13.099	-158.99	13.2	-159	0	0	159	42	180	4	24.8	S	f/999.0	500	-2
162	6	6	4/10/93	100/19:52:57.33	02/14:23:57	11.547	-158.01	11.6	-158	0	0	160	42	180	4	24.9	S	f/999.0	500	-2
163	6	7	4/10/93	100/19:53:26.16	02/14:24:26	10.419	-155.73	10	-157	0	0	160	42	180	4	24.9	S	f/999.0	500	-2
164	6	8	4/10/93	100/20:38:53.12	02/15:09:53	-8.796	13.249	-9	12	0	0	160	42	200	999	22.4	S	f/999.0	125	0
165	6	9	4/10/93	100/20:45:19.51	02/15:16:19	12.062	24.897	12.5	24.5	0	0	160	43	200	999	22.4	N	f/999.0	60	0
166	6	10	4/10/93	100/20:48:55.83	02/15:19:55	24.051	32.893	24.4	32.4	0	0	159	43	200	999	22.3	N	f/999.0	125	0
167	6	11	4/10/93	100/20:49:56.89	02/15:20:56	30.051	31.328	27.5	34.8	0	0	159	43	200	999	22.3	N	f/999.0	125	0
168	6	12	4/10/93	100/20:50:30.42	02/15:21:30	29.572	34.997	29.2	36.1	29.556	34.959	159	43	200	999	22.3	N	f/999.0	125	0
169	6	13	4/10/93	100/20:50:58.27	02/15:21:58	32.08	34.869	30.6	37.3	32.055	34.868	159	43	200	999	22.3	N	f/999.0	125	0
170	6	14	4/10/93	100/20:52:19.07	02/15:23:19	35.162	40.643	34.9	41.3	0	0	158	43	200	999	22.1	N	f/999.0	125	0
171	6	15	4/10/93	100/20:53: 2.77	02/15:24:02	36.378	43.136	36.9	43.3	0	0	158	43	200	999	22.1	N	f/999.0	125	0
172	6	16	4/10/93	100/20:54:16.02	02/15:25:16	40.032	48.536	40.5	47.5	0	0	158	43	200	999	22.1	N	f/999.0	125	0
173	6	17	4/10/93	100/20:59:55.68	02/15:30:55	54.989	73.384	53.5	73.4	0	0	157	43	200	999	22	N	f/999.0	125	0
174	6	18	4/10/93	100/22:21:43.44	02/16:52:43	32.411	15.096	31.9	15.5	0	0	159	44	200	999	22.3	S	f/999.0	500	-0.667
175	6	19	4/10/93	100/22:23:27.60	02/16:54:27	37.99	23.675	37.1	20.6	0	0	158	44	200	999	22.1	S	f/999.0	125	0
176	6	20	4/10/93	100/22:24: 1.55	02/16:55:01	38.011	23.743	38.6	22.3	38.006	23.703	158	44	200	999	22.1	S	f/999.0	125	0
177	6	21	4/10/93	100/22:24:29.89	02/16:55:29	38.046	23.797	40	23.9	0	0	158	44	200	999	22.1	S	f/999.0	125	0
178	6	22	4/10/93	100/22:25:24.33	02/16:56:24	41.087	28.962	42.4	27.1	41.044	28.913	158	44	200	999	22.1	S	f/999.0	125	0
179	6	23	4/10/93	100/22:46: 4.86	02/17:17:04	34.991	136.87	35.8	137.8	34.899	136.86	158	44	180	999	24.6	S	f/999.0	500	0
180	6	24	4/10/93	100/22:46:44.43	02/17:17:44	34.666	137.66	34	139.6	34.716	137.63	158	44	180	999	24.6	S	f/999.0	500	0
181	6	25	4/10/93	100/23:32:29.91	02/18:03:29	-31.62	-52.228	-32.3	-50.2	0	0	161	44	200	999	22.6	M	f/999.0	125	0
182	6	26	4/10/93	100/23:32:59.84	02/18:03:59	-29.97	-51.154	-30.8	-48.9	-30.03	-51.21	161	44	200	999	22.6	M	f/999.0	125	0
183	6	27	4/10/93	100/23:34: 1.02	02/18:05:01	-26.87	-48.595	-27.5	-46.2	-26.9	-48.63	161	44	200	999	22.6	M	f/999.0	125	0
184	6	28	4/10/93	100/23:34:49.73	02/18:05:49	-22.91	-46.949	-25.1	-44.3	-22.81	-47.02	161	44	200	999	22.6	M	f/999.0	125	0
185	6	29	4/10/93	100/23:52:21.12	02/18:23:21	33.686	-7.546	32.6	-6.8	33.625	-7.595	159	45	200	999	22.3	M	f/999.0	125	0
186	6	30	4/10/93	100/23:52:52.41	02/18:23:52	34.07	-6.769	34.1	-5.4	34.013	-6.824	158	45	200	999	22.1	M	f/999.0	125	0
187	6	31	4/10/93	100/23:53:21.95	02/18:24:21	36.222	-5.331	35.6	-4	36.171	-5.382	158	45	200	999	22.1	M	f/999.0	125	0
188	6	32	4/10/93	100/23:54:13.07	02/18:25:13	38.08	-1.068	38.1	-1.3	37.988	-1.13	158	45	200	999	22.1	M	f/999.0	125	0
189	6	33	4/10/93	100/23:54:42.62	02/18:25:42	39.54	-0.324	39.4	0.3	39.489	-0.386	158	45	200	999	22.1	M	f/999.0	125	0
190	6	34	4/10/93	100/23:55:16.03	02/18:26:16	41.47	2.199	41	2.2	41.47	2.198	158	45	200	999	22.1	M	f/999.0	125	0
191	6	35	4/10/93	100/23:59:20.05	02/18:30:20	50.338	19.049	51	19.9	50.297	19.109	157	45	200	999	22	M	f/999.0	125	0
192	6	36	4/11/93	101/00:02:11.34	02/18:33:11	55.791	37.637	55.6	36.7	55.822	37.515	157	45	50	4	88	M	f/999.0	125	0
193	6	37	4/11/93	101/00:15:16.06	02/18:46:16	39.441	111.83	39.3	111.1	0	0	158	45	50	4	88.6	M	f/999.0	125	0
194	6	38	4/11/93	101/00:16:13.07	02/18:47:13	36.947	116.58	36.7	114	37.027	116.58	158	45	50	4	88.6	M	f/999.0	125	0
195	6	39	4/11/93	101/00:16:44.18	02/18:47:44	35.099	115.38	35.2	115.5	0	0	158	45	50	4	88.6	M	f/999.0	125	0

APPENDIX E

MAST PAYLOAD ANNEX 2 INPUT

The below areas are listed in order of priority desired for scheduling.

Number	Area	Latitude	Longitude
1.	Eastern N.Pacific	20-00N	110-00W
		20-00N	145-00W
		50-00N	145-00W
		50-00N	110-00W
2.	North Sea	50-00N	010-00E
		50-00N	015-00W
		60-00N	015-00W
		60-00N	010-00E
3.	N. Pacific/ Bering Sea	45-00N	135-00W
		45-00N	165-00E
		60-00N	165-00E
		60-00N	135-00W
4.	Sea of Okhotsk	45-00N	140-00E
		45-00N	165-00E
		60-00N	165-00E
		60-00N	140-00E
5.	Eastern S.Pacific	15-00N	070-00W
		15-00N	135-00W
		60-00S	135-00W
		60-00S	070-00W
6.	E. North Atlantic	15-00N	010-00W
		15-00N	040-00W
		60-00N	040-00W
		60-00N	010-00W
7.	Eastern S.Atlantic	00-00	020-00E
		00-00	030-00W
		60-00S	030-00W
		60-00S	020-00E
8.	E. Indian Ocean	10-00S	120-00E
		10-00S	080-00E
		60-00S	080-00E
		60-00S	120-00E

9.	Sea of Japan	35-00N	125-00E
		35-00N	160-00E
		50-00N	160-00E
		50-00N	125-00E
10.	Mediterranean	32-00N	005-00W
		32-00N	040-00E
		45-00N	040-00E
		45-00N	005-00W
11.	Hudson Bay	50-00N	075-00W
		50-00N	095-00W
		60-00N	095-00W
		60-00N	075-00W

NOTES: (1) The above coordinates are for a 57 degree inclination orbit. For missions with a 28 degree inclination orbit, any above-listed latitudes exceeding 30 degrees N or S would therefore require a "cut-off" at 30 degrees N/S.

(2) The requested "swath of look" is 100 NM either side of ground track when the orbit falls within these regions. This equates to an approximate "look-angle" (zenith angle at nadir) of 30 degrees.

APPENDIX E - CONTINUED
MAST PAYLOAD ANNEX 3 INPUT

Lens/filter combination specifications.

The objective of the first MAST mission is to obtain good spatial resolution ship-track imagery in two basic types of scenes:

(1) Wide-area scenes which include a large number of shiptracks and/or the major portion of individual track(s).
(2) High-resolution scenes which contain the "head" and nearby surrounding area of a shiptrack.

This can be accomplished with the following combinations:

Camera	Lens	Approx. Distance Across Image	
Hasselblad	100mm	165 KM	90 NM
	250mm	65 KM	35 NM
Linhof	90mm	310x395 KM	170x215 NM
	250mm	110x145 KM	60x75 NM

Note: Assumes shot at nadir, 160 NM altitude.

It is understood that camera/lens combinations can be specified in the execute packages during the mission. However, as a general rule, it is anticipated that the Hasselblad with 100mm lens will be used to obtain shots with more of the shiptrack in the scene, while the Linhof with 250mm lens will be used for high-resolution track-head scenes.

For the first MAST mission, no IR or polarization filters, or IR film is desired. These can be utilized and experimented with on subsequent MAST missions, pending the assessment of the initial flight's results. Desired film type is 64 ASA.

MAST ground-station mission support was briefly discussed with Dr. David Pitts, EOL Flight Science Branch Manager. Our initial impression is that it would be desirable to have a separate support workstation located in the EOL area, either outfitted with a computer/software/monitor system supplied by the Naval Postgraduate School, or with existing EOL equipment (with some required upgrades). An Ethernet connection will be required. In any case, the intent is to preclude interference with the normal EOL operational mission support functions, while at the same time mutually benefitting from the considerable multi-technical experience and talent which is available. Some type of personal interface with the CSR or POCC (either via a shift rep or scheduled daily briefing) would probably be beneficial as well. Further discussion concerning the ground support issue will be necessary.

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